BEST
Bioenergy and Sustainable Technologies

Learnings from Biomass combustion towards future bioenergy applications

CEBC 2023, BEST day
Jan 18, 2023

Manuel Schwabl & Elisabeth Wopienka

FFG Forschung wirkt.
Bundesministerium Arbeit und Wirtschaft
Bundesministerium Klimaschutz, Umwelt, Energie, Mobilität, Innovation und Technologie
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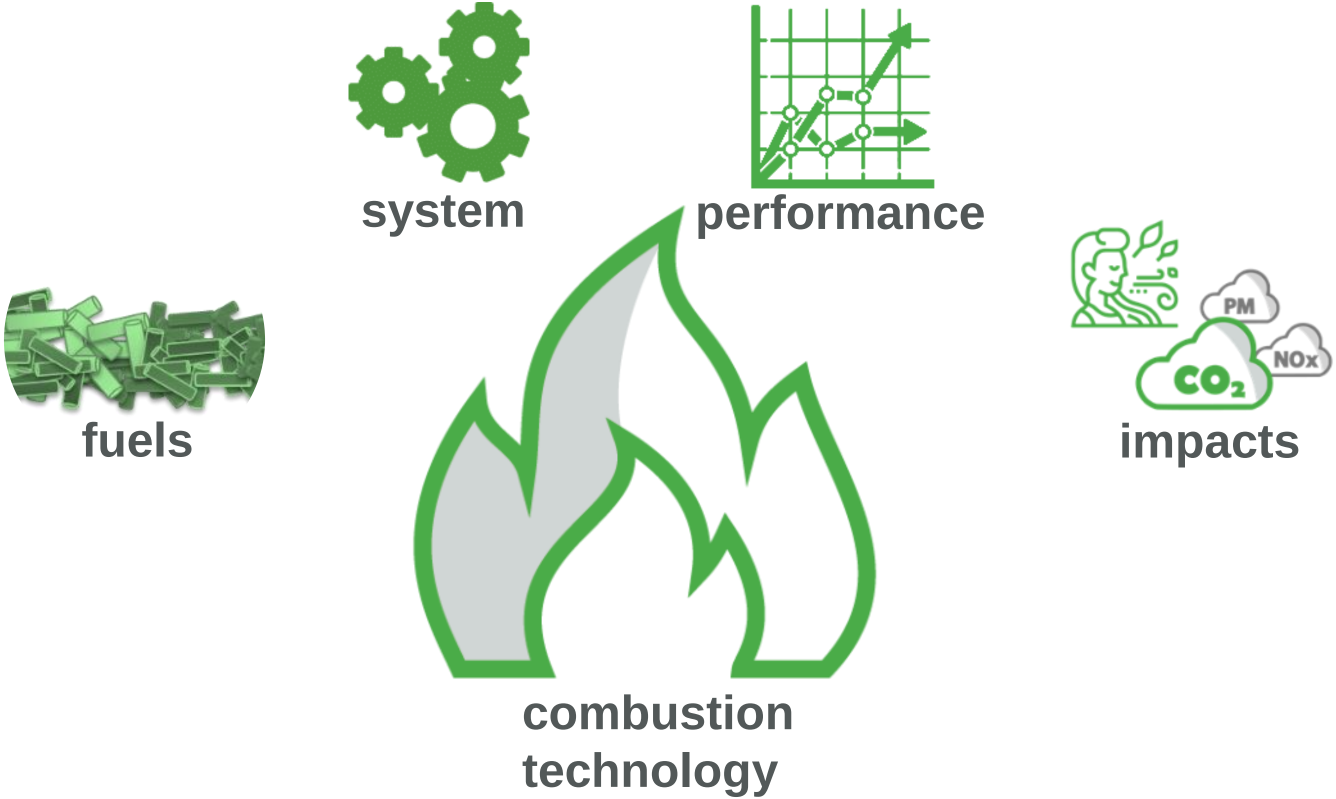
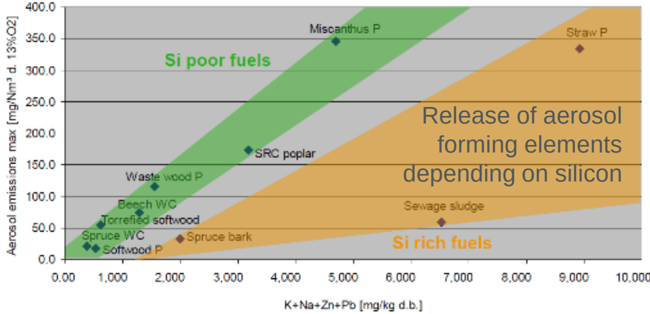
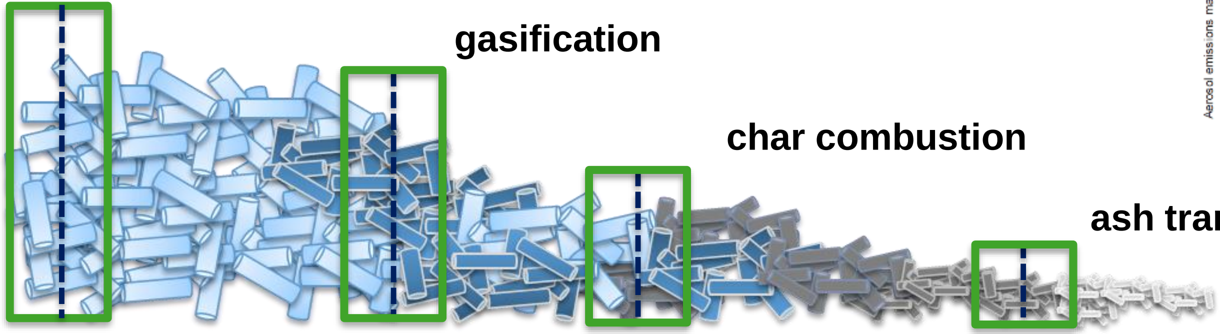
Learnings from the evolution of combustion technology



Fuel impacting combustion

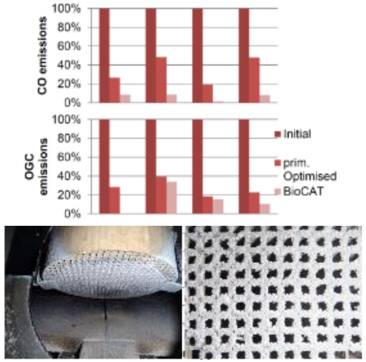
- Release and retention of compounds in different phases of combustion
- Characterisation of fuels in laboratory methods



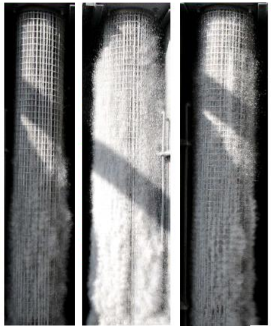


System combinations

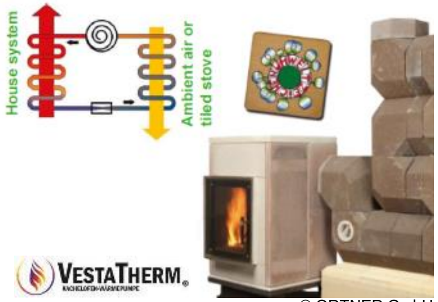
- Interaction between technologies are important to be understood
  - During operation
  - Technology requirements



Emission abatement by catalysts in stoves



Cleaning of filter bags



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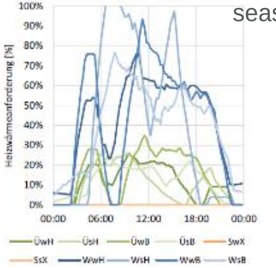
Accumulating stove dissipates heat to house via heat pump

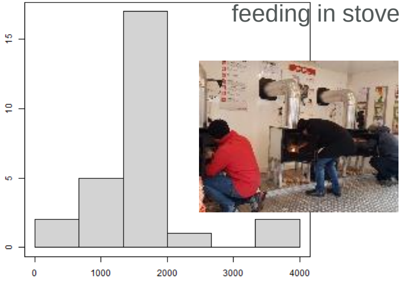
Stirling engine in pellet boiler

Real-life behaviour

Daily residential heat demand at different season days

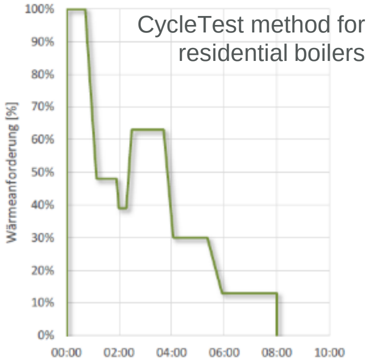


Variance of fuel mass feeding in stove



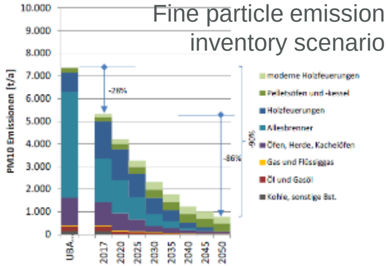
- No constant conditions
- Demand oriented
- User behaviour
- Real-life testing methods allow user centric developments

CycleTest method for residential boilers



Emission and impacts

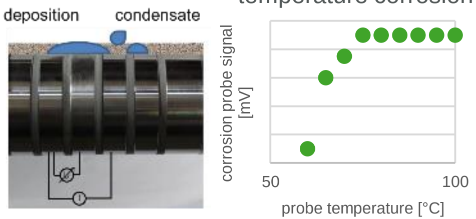
- Methods for monitoring and measurement need to be effective and practicable
- Communication and awareness raising



Fine particle emission inventory scenario

Citizen science approach in CleanAir workshops

probe for low temperature corrosion

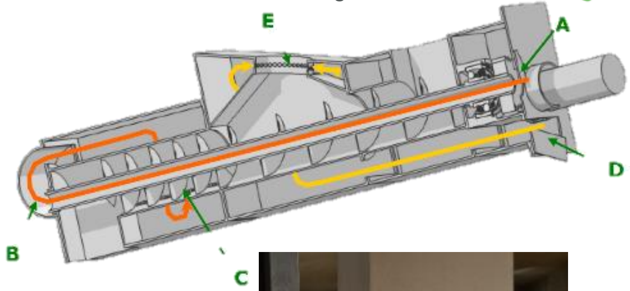


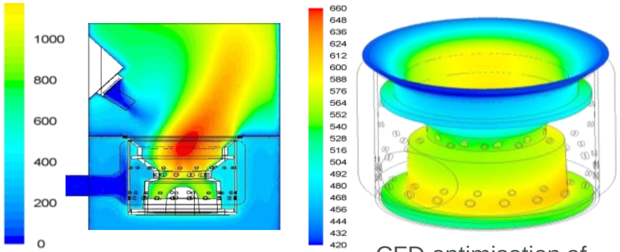
simplified BaP measurement method

Technology development

- Opening up to new biomass fuel segments
- Applying newest methods and know-how for innovating combustion technologies

Auger burner





CFD optimisation of pellet burning pot

Briquette candle stove „Mr. Wu“ Austroflamm

Thanks to our partners

… and many more

Thanks to our funding partners

…

Conclusions

Feedstock characteristics and lab scale testing. Testing feasibility and applicability of feedstocks

System compatibility. Technology combinations and hybridisations state the basis for a diverse and multi-adaptive bioenergy system.

User centric technology development. Optimizing technology for user not for meeting standards

Social and environmental responsibility. Knowing and sharing the impacts

The USP in future renewable energy system. Renewable energy systems are highly diverse – every system has strengths and weaknesses.

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GreenCarbon perspectives for regional sourcing and decarbonization

CEBC 2023, BEST day
18 Jan, 2023

Elisabeth Wopienka & Manuel Schwabl

Challenges in thermal biomass utilization

- Sustainable and **economical use of resources**
- **Decarbonization strategies** for raw material and energy supply
- Creation of **carbon sinks**

- **Cascaded utilization** and **material & energy cycles** play a major role
- Technology development perspective needs to consider **process chains** and **system integration of technologies** rather than development and optimization of individual technologies.

Quelle: https://ellenmacarthurfoundation.org

Expertise & learnings from past activities

Know-how on

- Feedstock properties and conversion characteristics
- Thermochemical conversion processes
- Lab test methods for various conversion conditions
- Methods on (user centric) technology development

Guiding principles

- Special consideration of system compatibility & real-live performance
- Environmental and social impact
- Focus on USP in future energy systems and circular economy

Thermochemical Technologies‘ potential

Interim solution & Energy storage

- in energy systems

Upgrading of (biogenic) residues

- Final step in cascaded paths of use
- Carbon-Recycling
- Sanitation of particular residuals

Decarbonization – GreenCarbon & Energy

- Regional sourcing
- CO_2-sink
- Circular economy

Increasing **added value**, contributing to **security of supply** and opening up **decarbonization potential** by producing **carbon products & energy from renewable raw materials** and residues.

Thermochemical Technologies` focus

Optimal use of residual material potential with high variability

Fixed bed gasification & pyrolysis

Small- & medium scale (robust) technological concepts

Energy/technology integration

Technology- & process development in cooperation with *Area 2 Digital Methods & Solutions*

GreenCarbon products with regional applicability AND/OR high energy density AND/OR high added value

Economical and ecological assessment of value chain / cycle with *Area 3*

Fixed-bed gasification – Infrastructure & research focus

Technology development

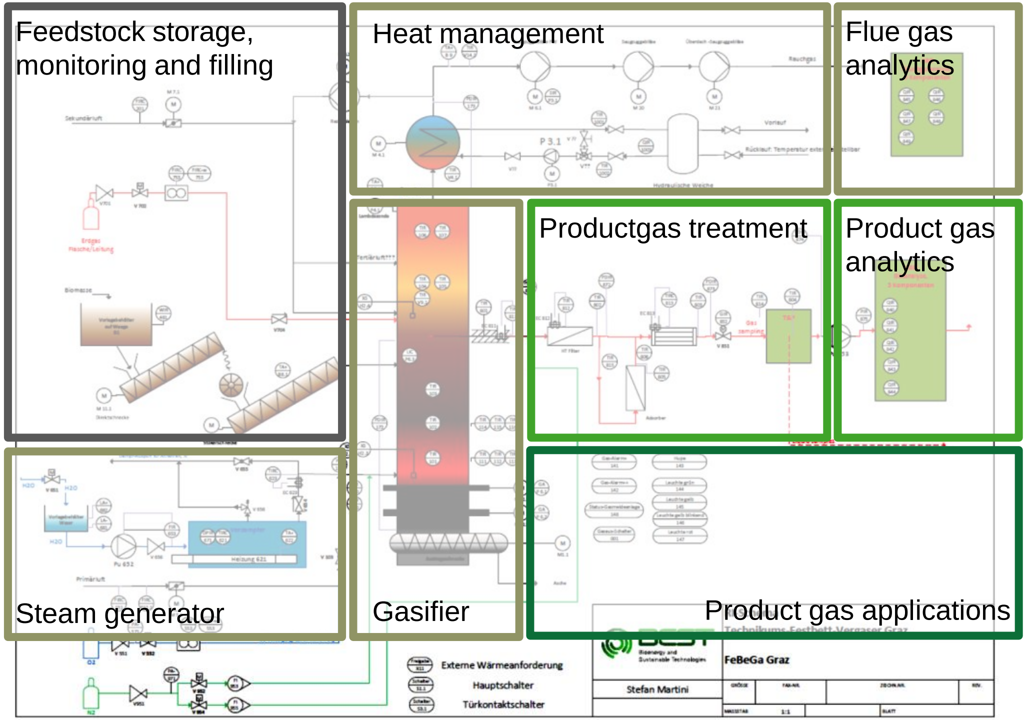
- Fuel-flexible technologies
- Scale-up

Product gas – quality

- O_2/steam gasification tests
- Gas cleaning
- Feedstock variation

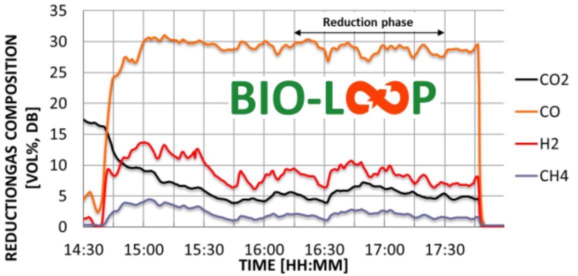
Product gas – applications

- Burners
- Engines
- Chemical looping
- Production of base chemicals



Fixed-bed gasification – Ongoing activities, upcoming projects & topics

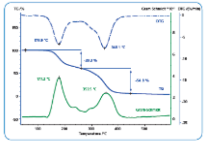
- Technology development:
  - **Oxygen-steam-gasification** for low-nitrogen product gas to be used in a chemical looping process
  - **Scale-up** & **fuel-flexibility** of fixed-bed gasification

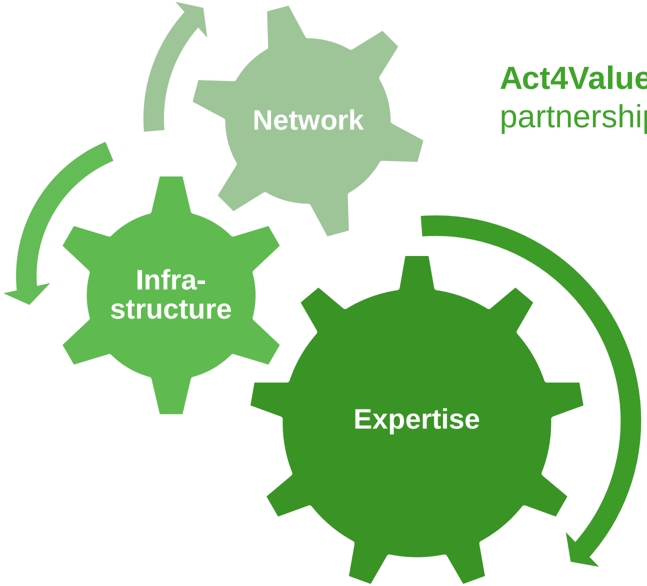


- Feedstock-variation & fuel flexibility
  - Conversion properties of **agricultural residues and biomass-plastics mixtures**

- Char-utilization
  - Applicability as **additiv for composite materials** with specific electrical properties

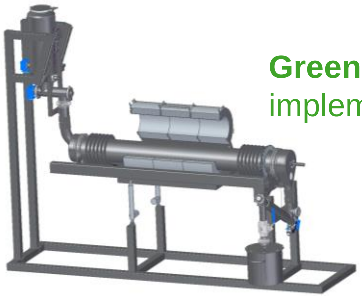
Pyrolysis –
Infrastructure & framework conditions





Act4Value partnership

- Research and science
- Economy
- Education
- Administration
- Society



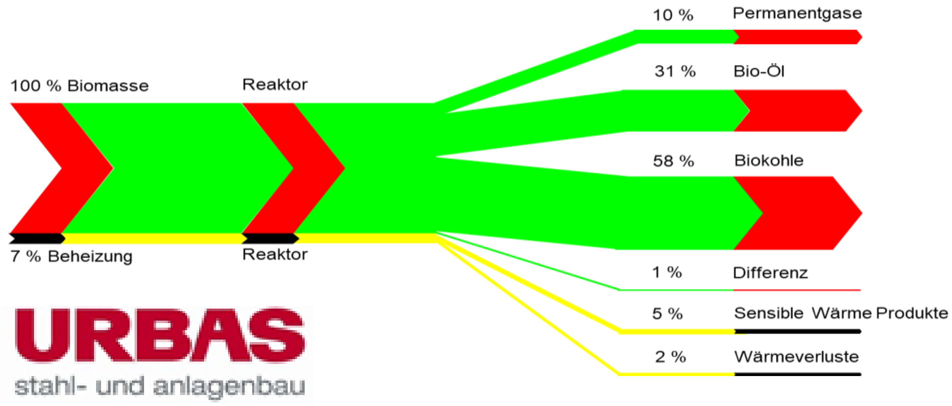
GreenCarbon Lab
implementation 04/2023

Basic research / Know-how
conversion behaviour, product properties, etc.

Europäische Union Investitionen in Wachstum & Beschäftigung. Österreich.

Pyrolysis –
Ongoing activities, upcoming projects & topics

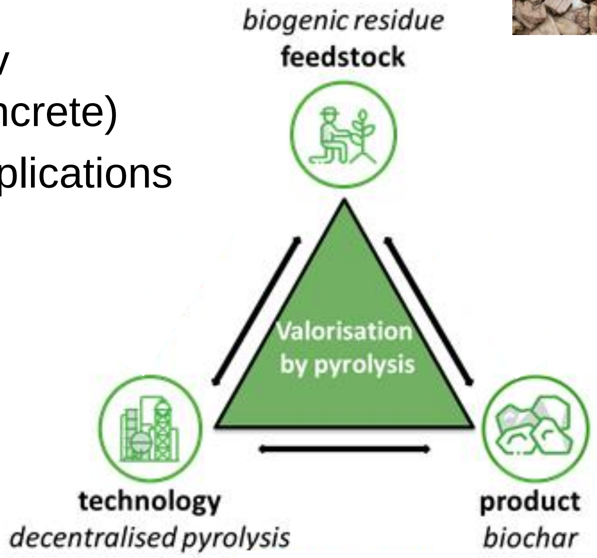
- *Bio-Holzkohle-KWK* – production of barbecue charcoal

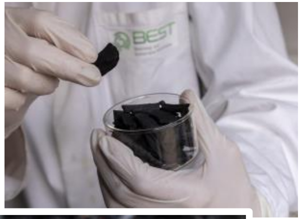


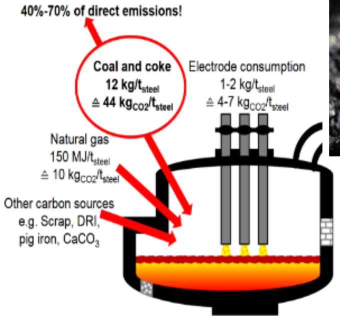
Pyrolysis –
Ongoing activities, upcoming projects & topics

Evaluation of **GreenCarbon qualities** for particular applications

- Metallurgy
- Material additiv (plastics or concrete)
- Agricultural applications







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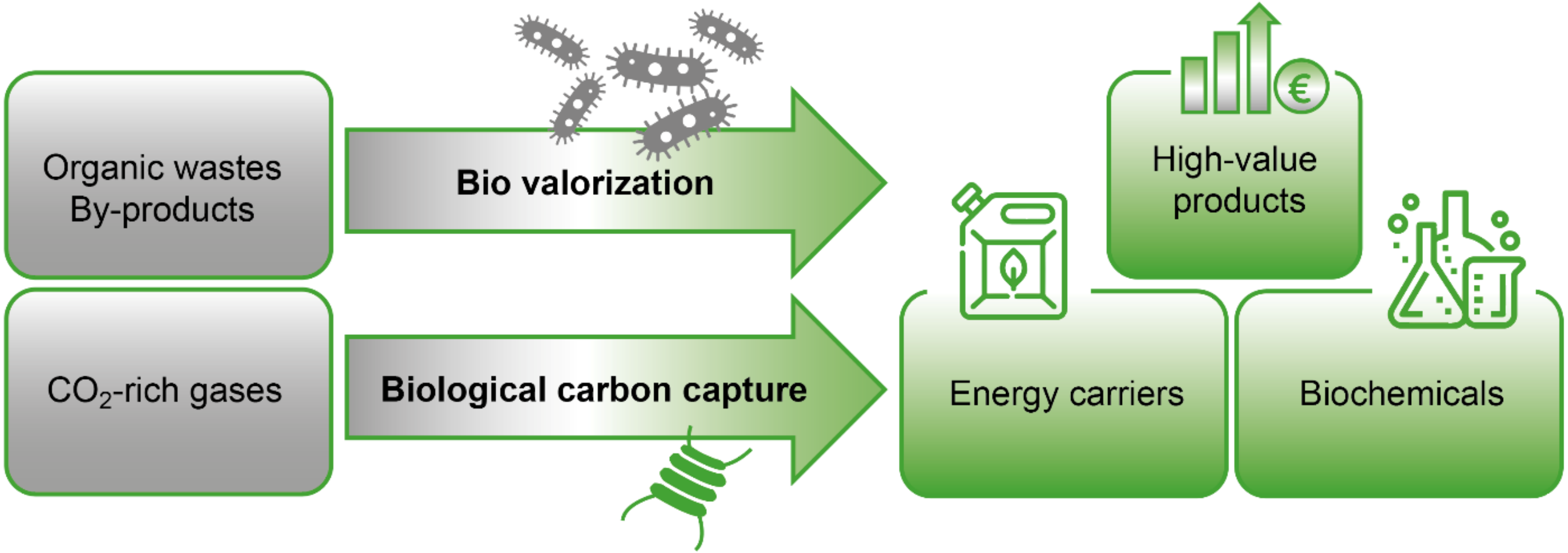
Bioconversion processes for renewable energy and/or biological carbon capture and utilization

CEBC 2023, BEST day
Jan 18, 2023

Bernhard Drosg

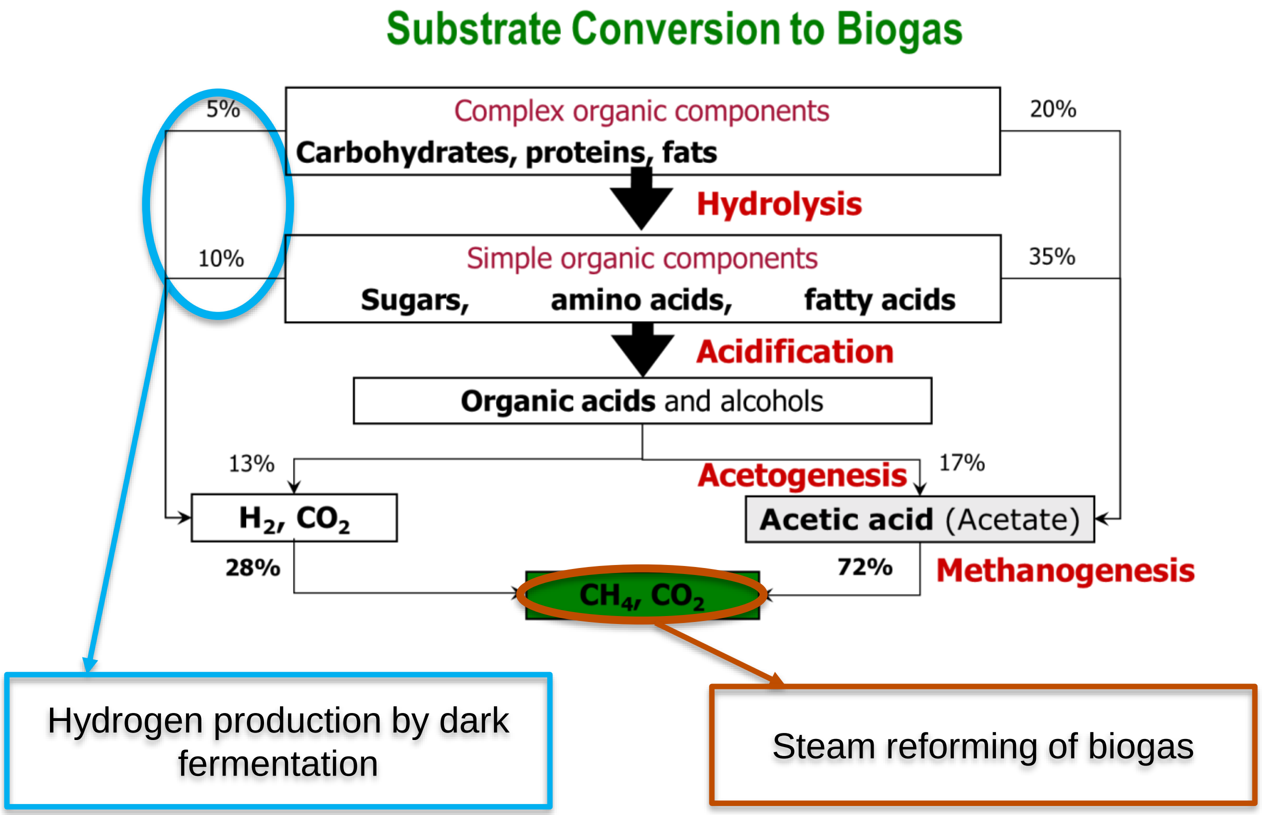
Overview bioconversion processes



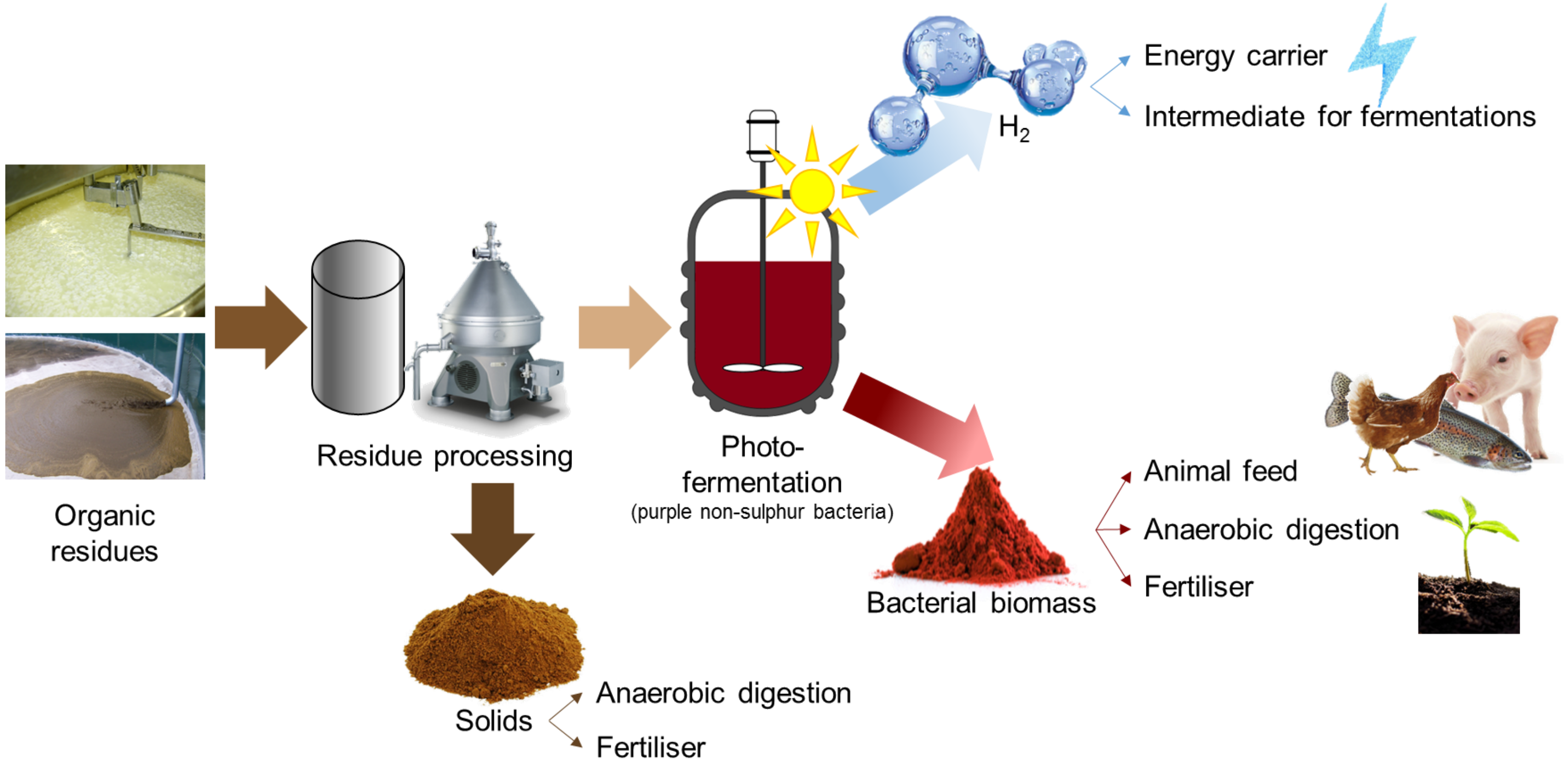
Bio-valorization of organic wastes and by-products to bioenergy

Biogas / bio-methane production

Biohydrogen production from biogas process

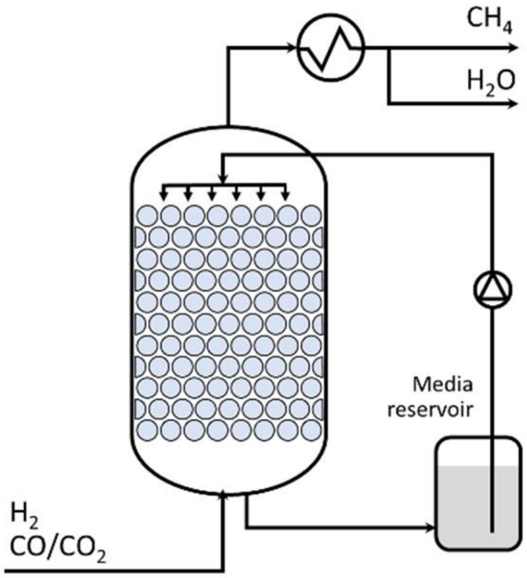


Biohydrogen production by purple bacteria



Gas fermentation - biological carbon capture and utilization

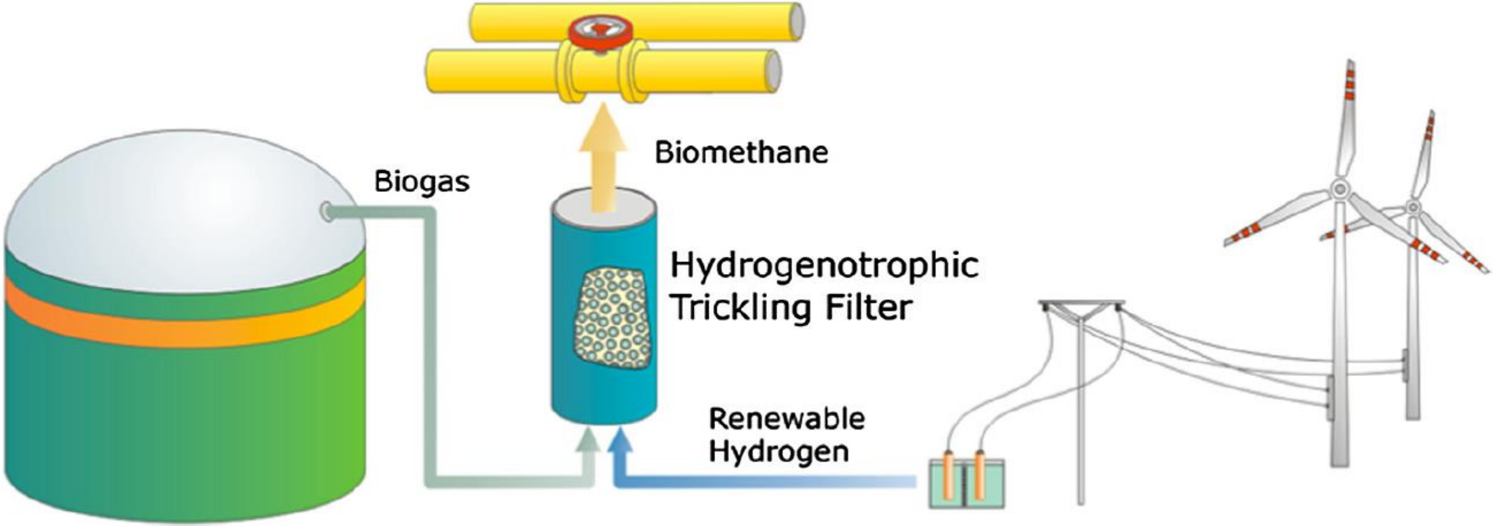
Gasfermentation –
to valorize CO_2-rich gases



- Alternative routes
  - Acetic acid (homoacetogenesis)
  - Longer chains (e.g. syngas, electro-fermentation)
- Trickle-bed reactor:
  - Good balance between maximum gas transfer and energy input
  - High internal surface area
  - Sturdiness and reliability

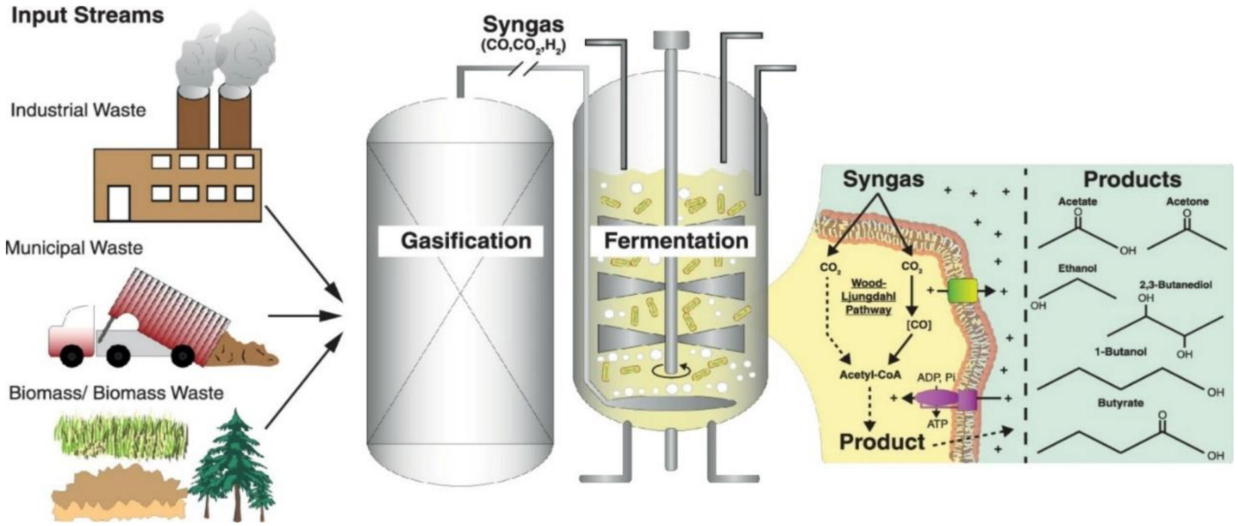
Biotechnological process is much less demanding on gas quality and removal of impurities

Gas fermentation –
upgrading biogas to biomethane



Source:
Rachbauer, L; Voitl, G; Bochmann, G; Fuchs, W Biological biogas upgrading capacity of a hydrogenotrophic community in a trickle-bed reactor. APPL ENERG. 2016; 180: 483-490

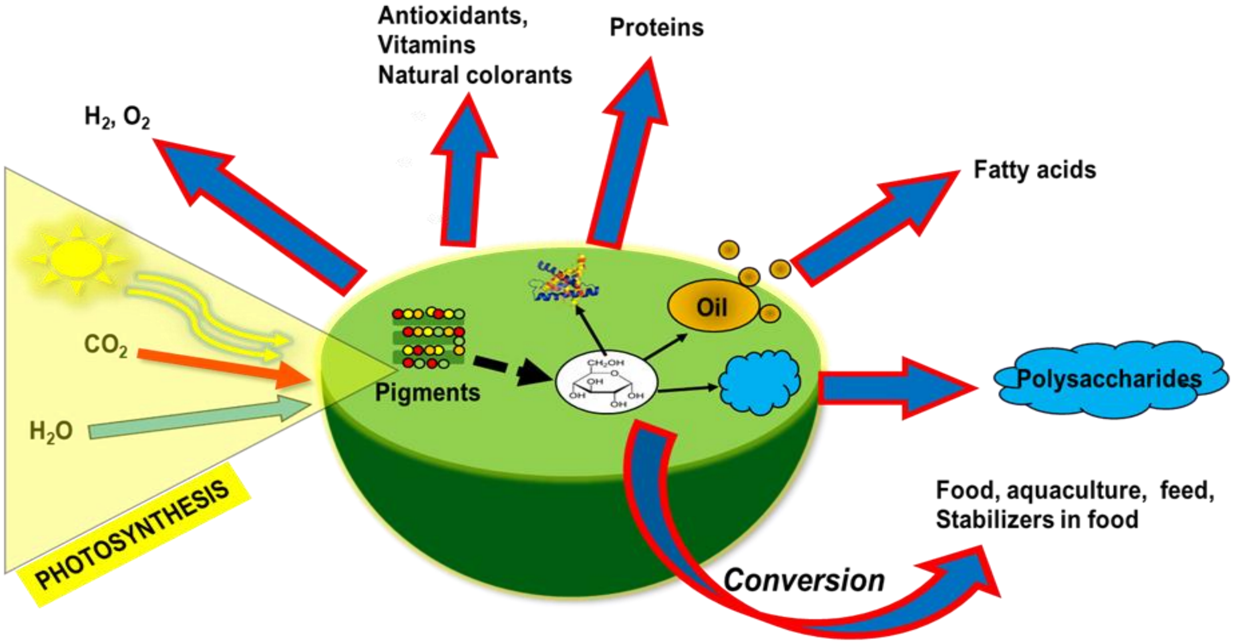
Gas fermentation –
Upgrading wastes by syngas fermentation



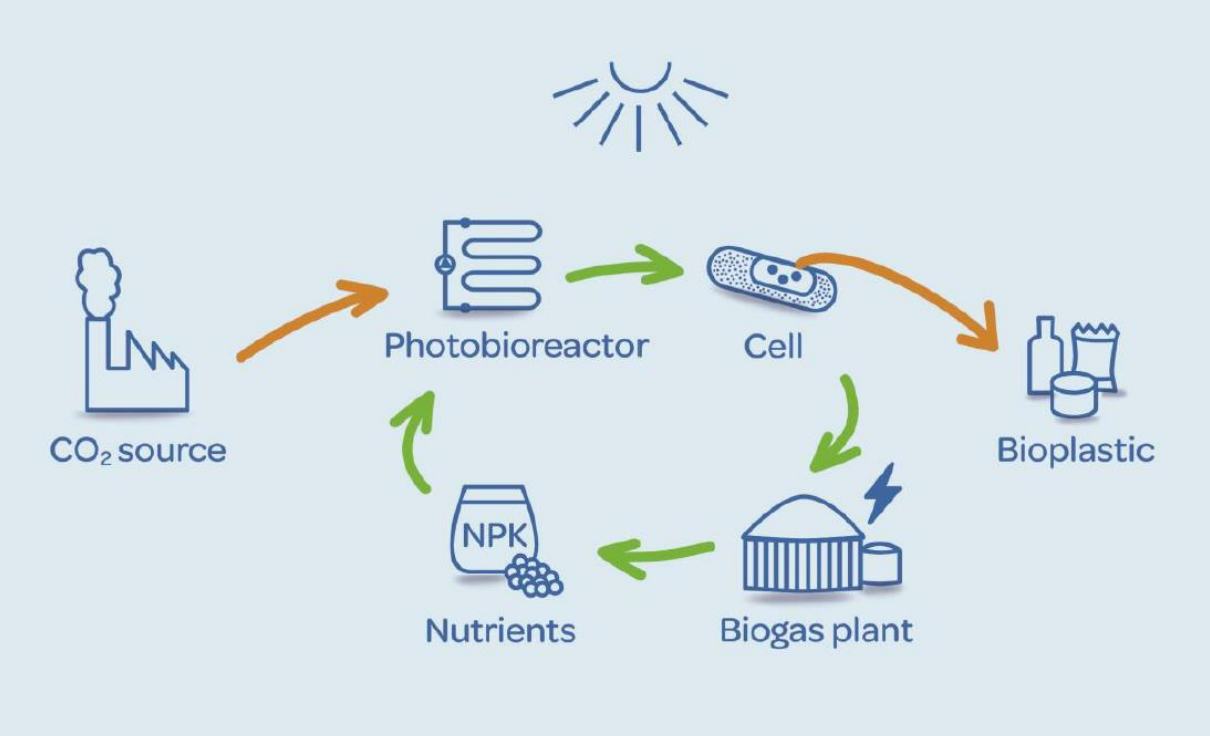
Source:
Latif H, Zeidan A, Nielsen A, Zengler K (2014) Trash to treasure: production of biofuels and commodity chemicals via syngas fermenting microorganisms, Current Opinion in Biotechnology 27, 79-87.

Microalgae processes - biological carbon capture and utilization

Microalgae biorefinery



Biopolymer production from CO_2 by cyanobacteria



CO_2 utilization in photobioreactor at power plant

Left: Photobioreactor; Right: Amine scrubber for CO2 purification

EVN

ANDRITZ

BOKU

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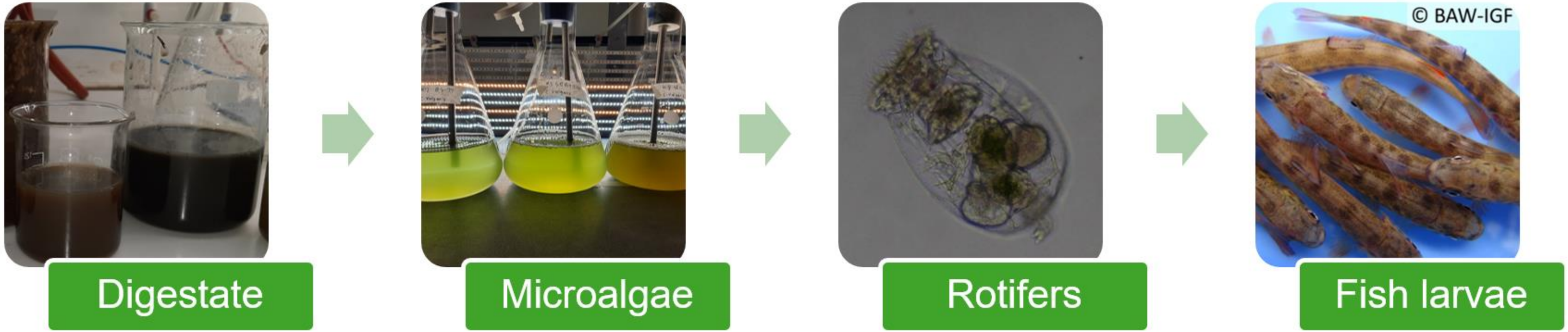
From biogas digestate and CO_2 to fish feed



→ Interreg Project ATCZ221 Algae4Fish

Interreg Austria-Czech Republic
European Regional Development Fund
EUROPEAN UNION

Algae biomass as food

Algae4Food

Cultivation of microalgae → Processing of biomass → Food design → Commercial-isation → Market

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Conclusions

- Microbes are very flexible to be applied for industrial processes
  - They work at low temperatures,
  - have low energy demand and
  - can deal with a wide range of impurities
- Wastes and biomass can be converted to energy carriers and chemicals
- CO_2-rich gases can be used as carbon source instead of sugars (bio-CCU - biological carbon capture and utilization)
- Different degrees of technical maturity
- High potential of combining thermo-chemical and biological processes (e.g. syngas fermentation)

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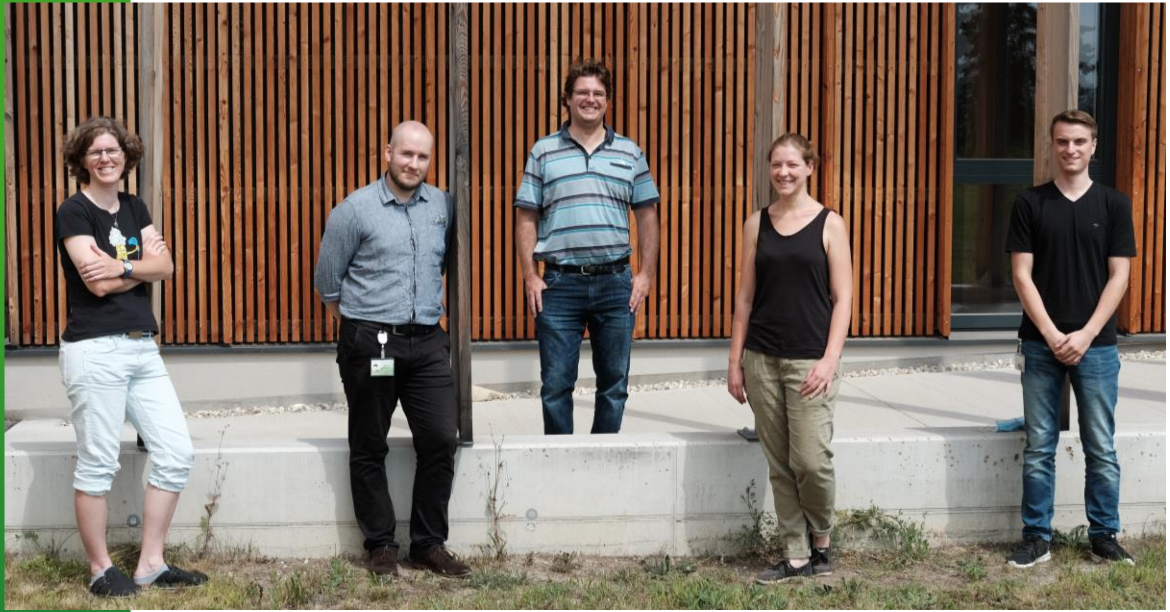

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Bioenergy and Sustainable Technologies

Second generation biomass gasification: Syngas Platform Vienna - current status and outlook

CEBC 2023, BEST day
Jan 18, 2023

Matthias Kuba

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Für die Stadt Wien
Das Land Steiermark
Wirtschaft, Tourismus, Regionen, Wissenschaft und Forschung
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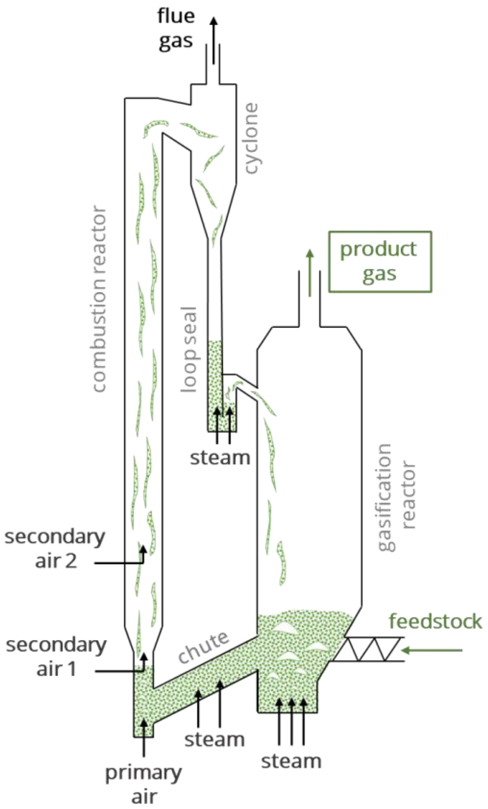
Demonstration in Wien Simmering

Target	Production of syngas from biomass and waste and downstream synthesis
Scale	1 MW **DUAL FLUID** gasification 250 kW Fischer-Tropsch synthesis
Operation	Campaigns for research operation
Fuel	wood chips, sewage sludge, plastic waste, sorted waste, agricultural residues

DFB: Woody biomass as input
1st reactor design



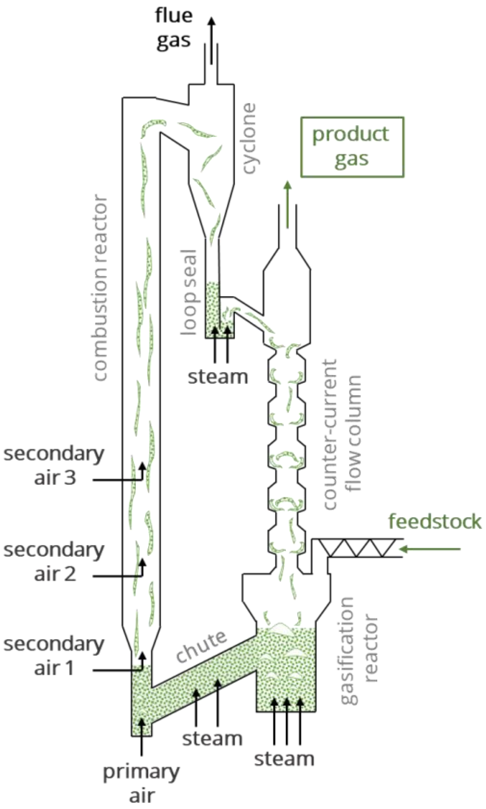
DFB Design
1. Roll-out

Gasification Reactor: bubbling fluidized bed with freeboard above.

Light material and volatiles are not in well contact with bed material and cannot be intermixed in the fluidized bed

Low conversion, high amounts of undesired tars in the product gas.

DFB: Residues and waste as input
2nd reactor design



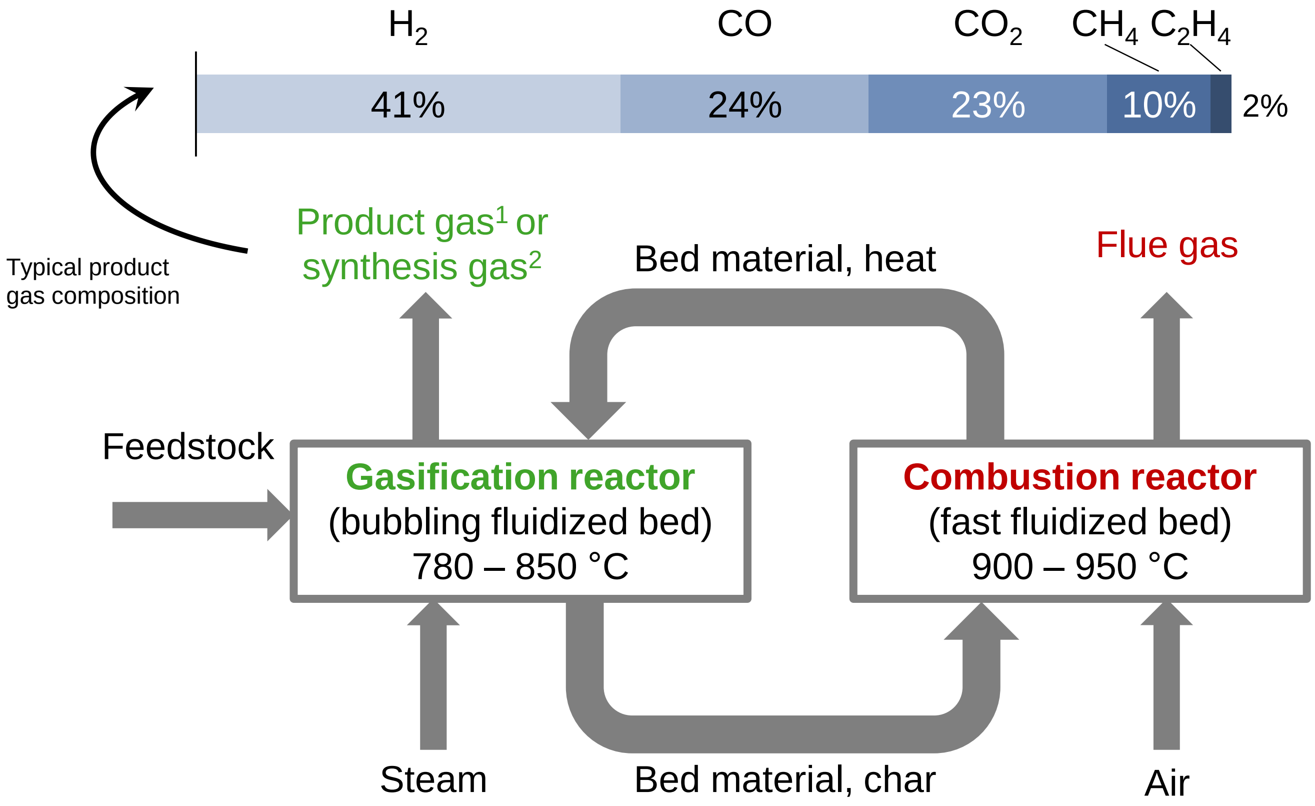
DFB Improved Design
2. Roll-out

Gasification Reactor: Bubbling fluidized bed with counter-current flow column above.

Light material and volatiles are now in well contact with bed material as they are forced to be in contact in the counter-current flow column.

Higher conversion, lower amounts of undesired tars in the product gas.

Syngas from DFB gasification



1 e.g. tar (incl. BTEX): 20-30g/m³, H_2S ~100 ppm for biomass fuel before any gas cleaning for downstream processing

2 Synthesis gas = cleaned from impurities

Location Overview

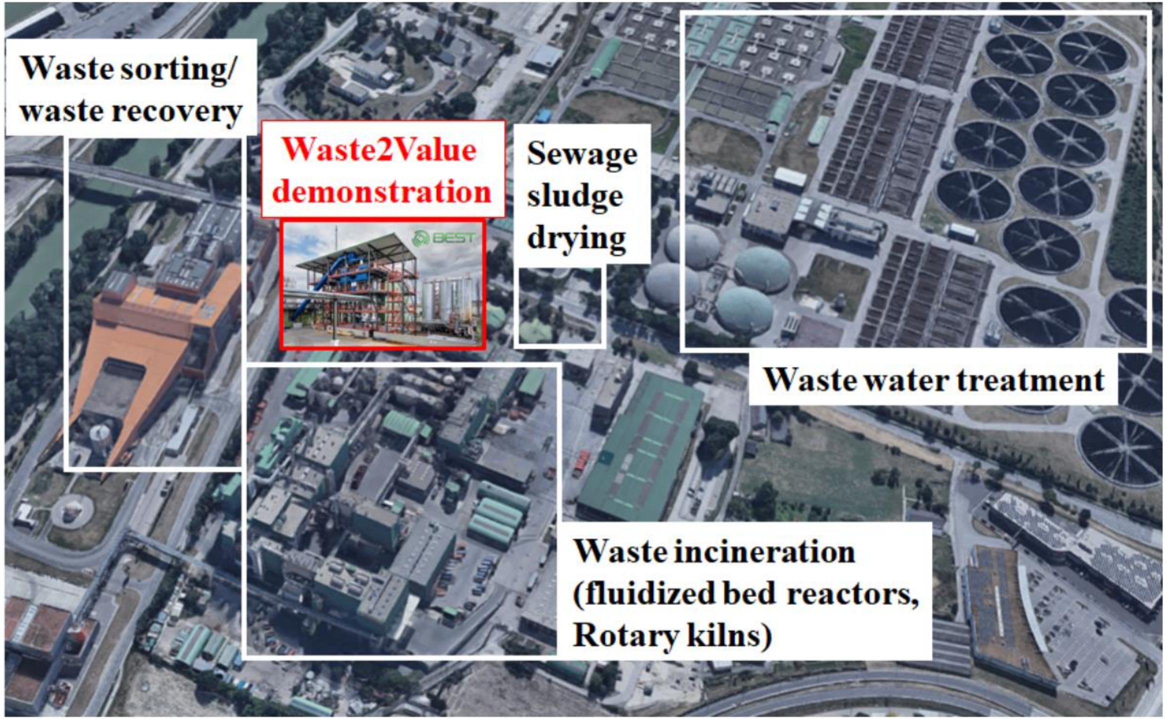
Vienna, City Center

Syngas Platform Vienna location

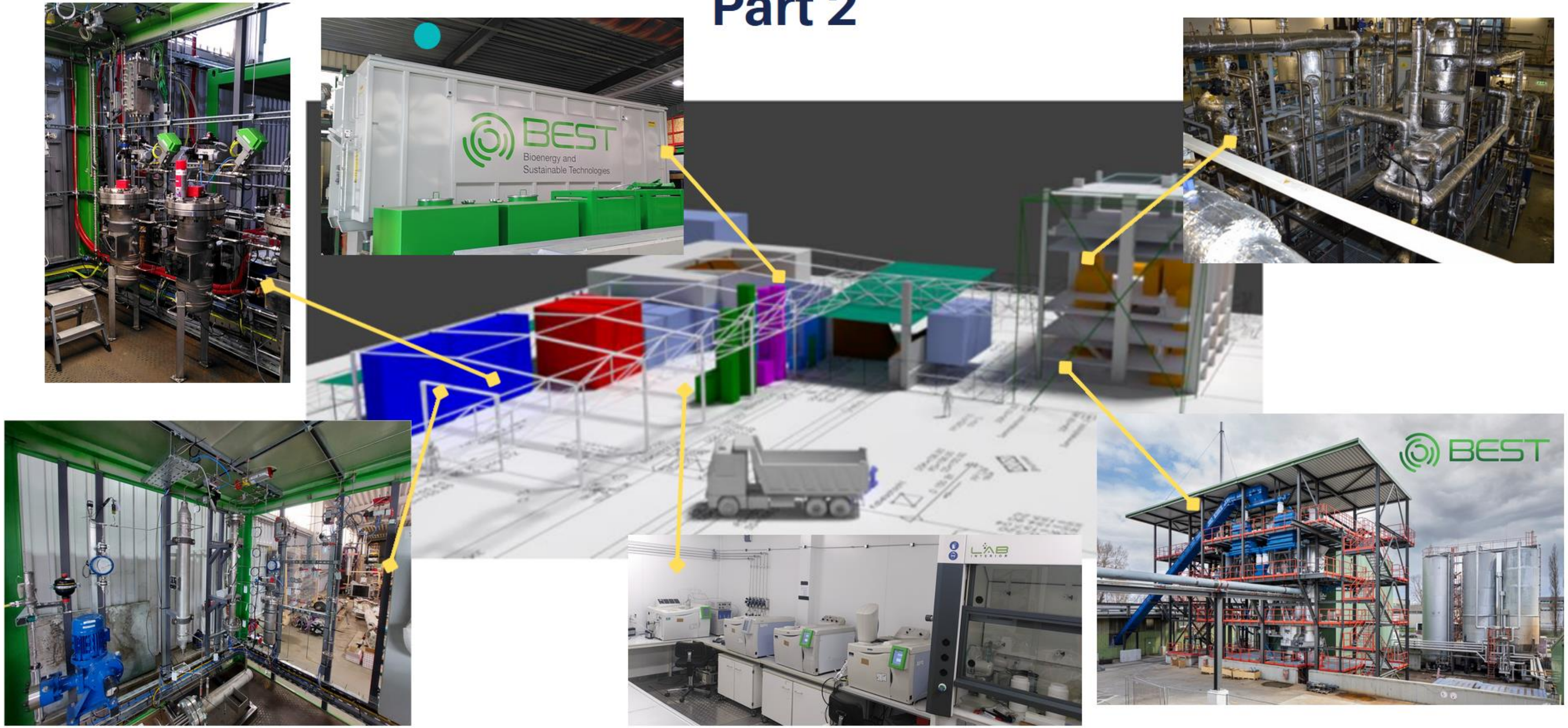
The demo plant (waste to liquid fuel & green gases) is located in the city of Vienna, halfway between the airport and the city center.

Airport VIE

Creating a versatile research location Part 1



Creating a versatile research location
Part 2



Creating a versatile research location
Part 3

Syngas Platform Vienna

Shifting Research Focus

Syngas Platform Technologies

Residues and waste
forestry, agriculture,
industry and WWT

Optional: Peak-wind energy

Refinery products
- Wax
- Jet Fuel
- Alcohols
- Diesel

Gases
- Hydrogen
- SNG
- Syngas combustion

CHP
- Electrical
- Thermal

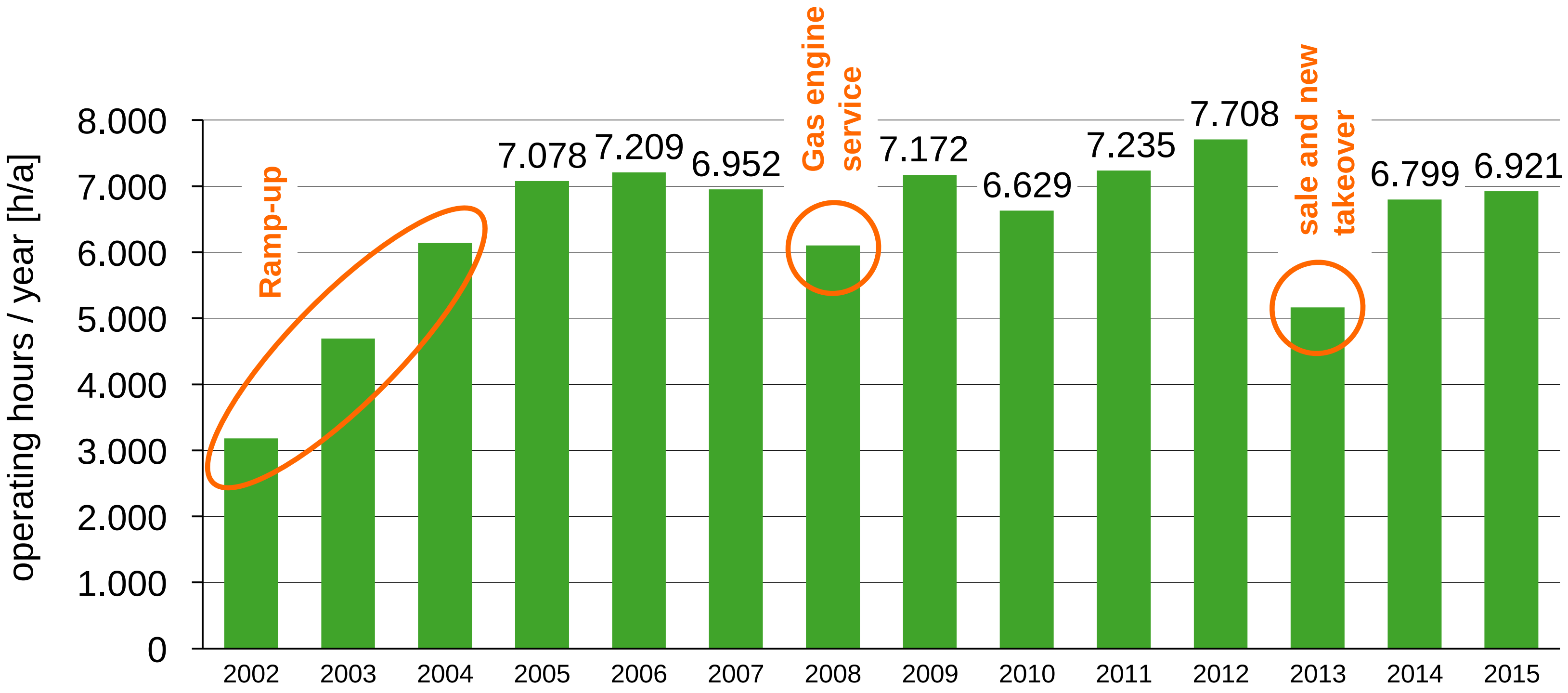
Shifting Research Focus

Dual Fluidized Bed – Experience from the 1st generation

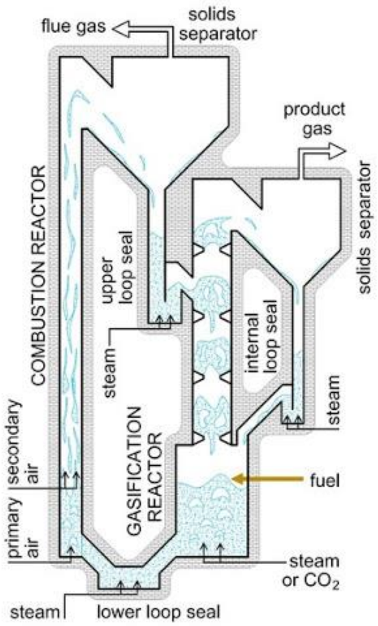
- <u>Experience</u>: 200.000 operation hours (cumulative)
- <u>Technology development</u>: Learning from mistakes
- <u>Different scales</u>: Based on lab-scale, learned from industrial-scale, back to demo-scale for new setting

Commercial DFB Plants

Yearly operating hours of Güssing DFB (1st generation based on woody biomass)



Fuels already tested in second generation 100 kW DFB pilot plant at TU Wien



Versatile operation in DFB system

„classic“ DFB

Up to **32 MW** DFB steam gasification. Commercial operation for combined heat and power production, using woody feedstock.

More H_2 in product gas

SER - DFB

Lab-scale tests show over **70 vol% H_2** **S**orption **E**nhanced **R**eforming (SER),

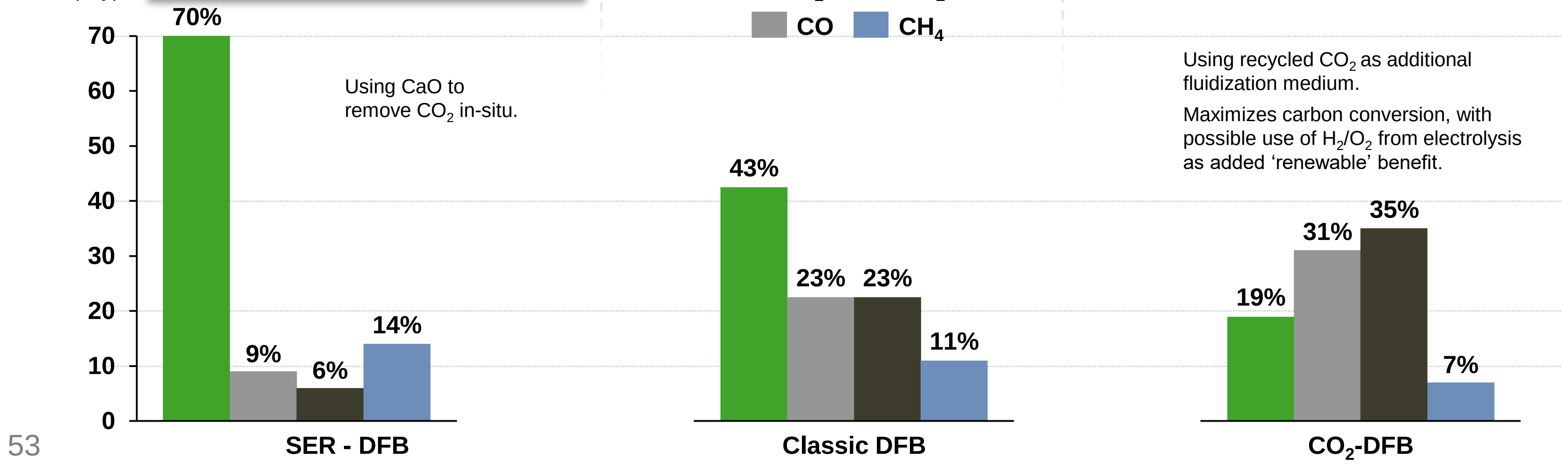
Product gas contains more hydrogen, but less CO and CO_2

More CO in product gas

CO_2 - DFB

Lab-scale tests show an increased **CO** yield of +**30 %**

Low H_2/CO ratio, increased carbon conversion rate



BEST

Target	Production of syngas from biomass and waste and downstream synthesis
Scale	1 MW **DUAL FLUID** gasification 250 kW Fischer-Tropsch synthesis
Operation	Campaigns for research operation
Fuel	wood chips, sewage sludge, plastic waste, sorted waste, agricultural residues

The BEST TEAM

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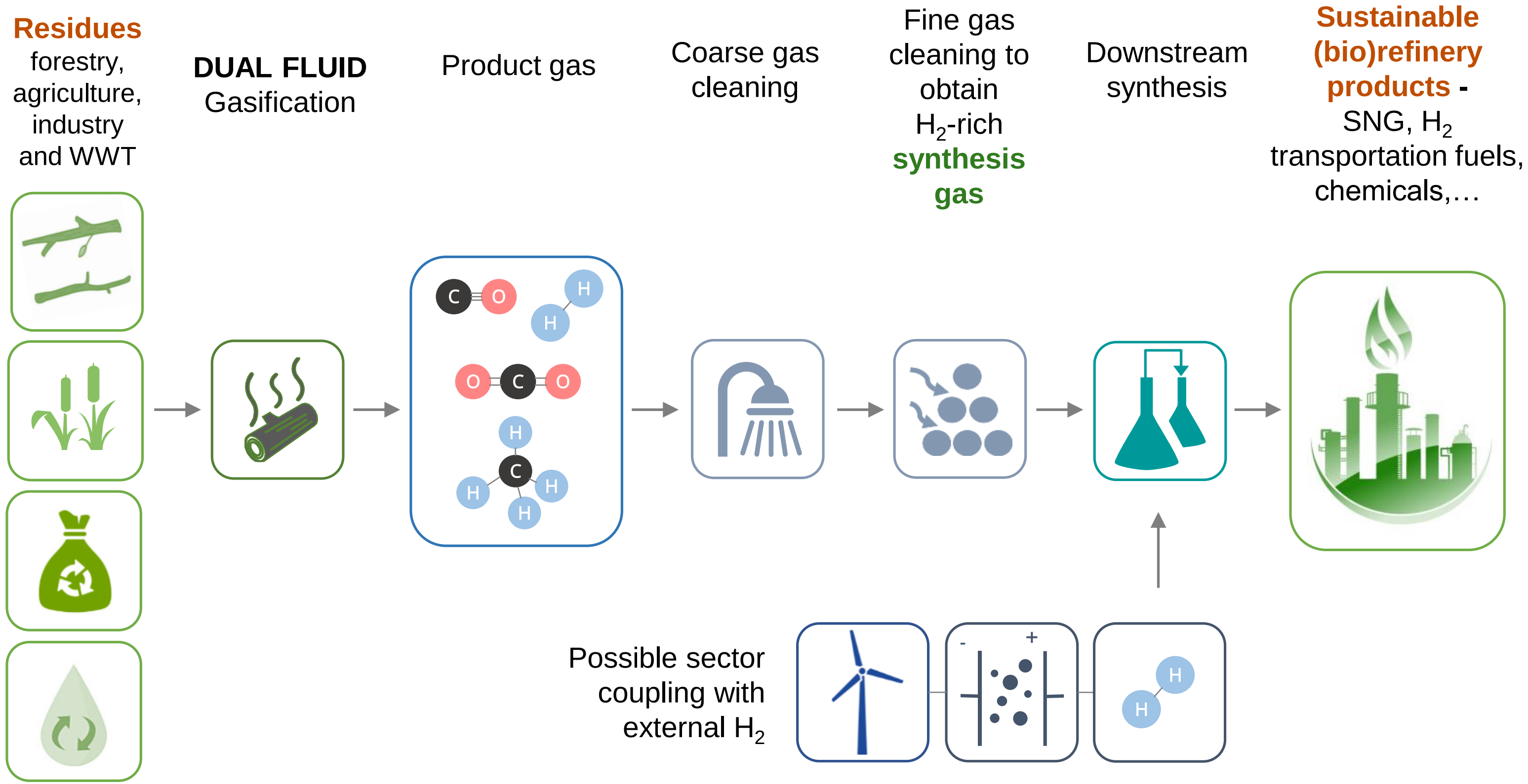
Utilization of Syngas for the Production of Fuel and Chemicals – Recent Developments and Outlook

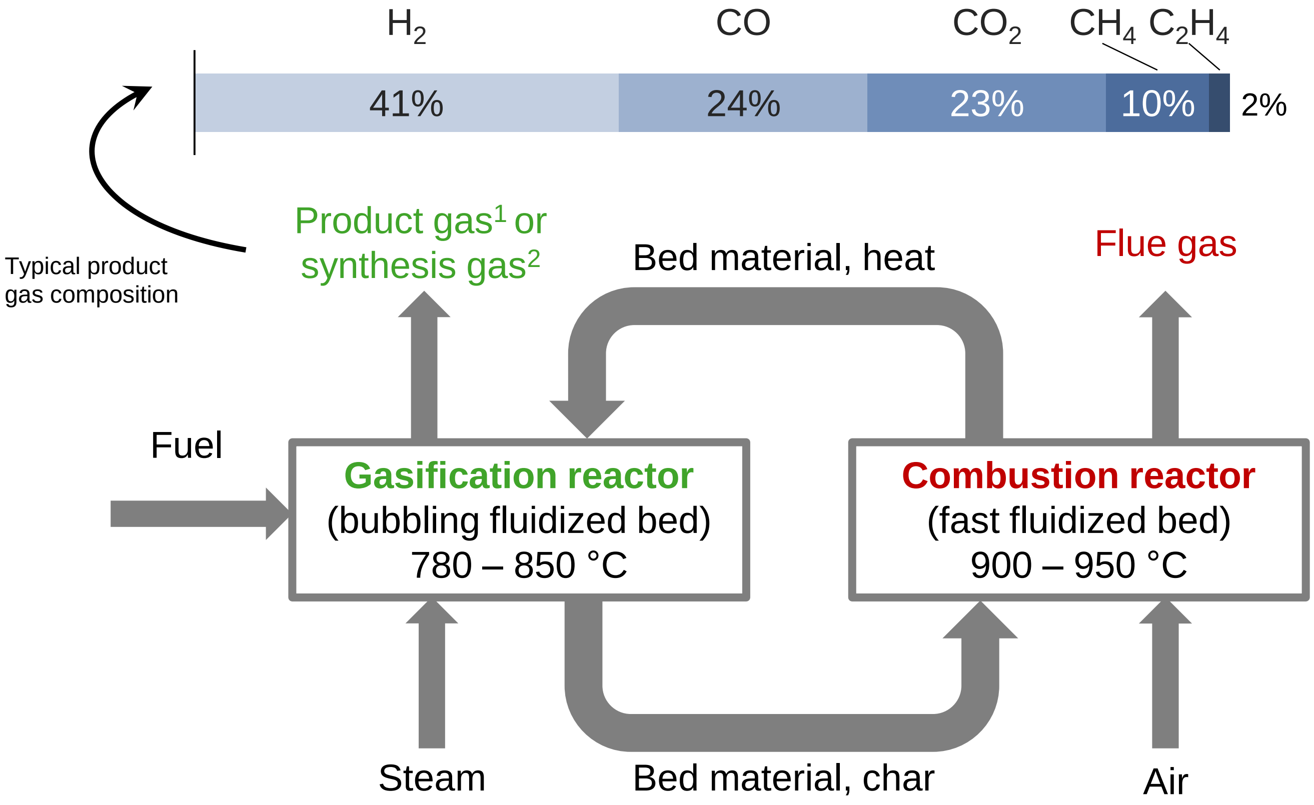
CEBC 2023, BEST day
Jan 18, 2023

Gerald Weber

Process Overview

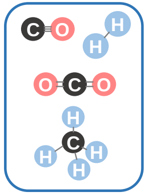


CO/H_2 Production with DUAL FLUID gasification

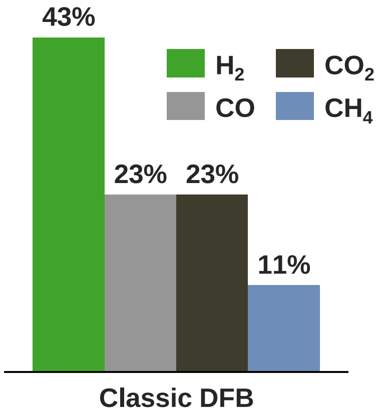


1 e.g. tar (incl. BTEX): 20-30g/m³, H_2S ~100 ppm for biomass fuel before any gas cleaning for downstream processing

2 Synthesis gas = cleaned from impurities



Product Gas Composition („classic “ DUAL FLUID)



Main components		
H_2	35-45	$vol\%_{dry}$
CO	19-23	$vol\%_{dry}$
CO_2	20-25	$vol\%_{dry}$
CH_4	9-11	$vol\%_{dry}$

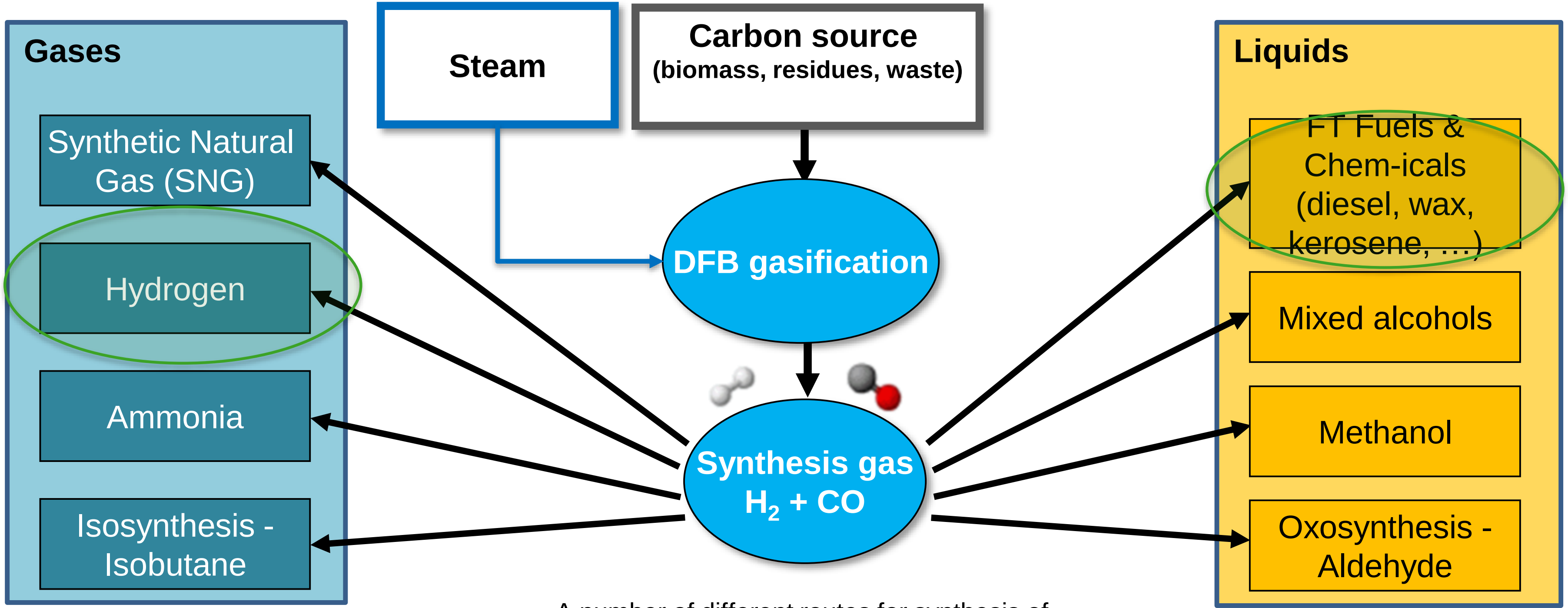
H_2:CO = from 1.5:1 to 2:1

Minor components		
C_2H_4	2-3	$vol\%_{dry}$
C_2H_6	~ 0.5	$vol\%_{dry}$
C_3H_8	~ 0.5	$vol\%_{dry}$
O_2	< 0.1	$vol\%_{dry}$
N_2	~ 1	$vol\%_{dry}$
Particles	30-100 (after gasifier)	g/Nm^3
Tars	1-5 (after gasifier)	g/Nm^3
BTX	~ 10	g/Nm^3

Catalyst poisons		
H_2S	~ 150	ppm_V
COS	~ 5	ppm_V
Mercaptanes	~ 30	ppm_V
Thiophene	~ 7	ppm_V
HCl	~ 3	ppm_V
NH_3	500-1,500	ppm_V
HCN	~ 100	ppm_V

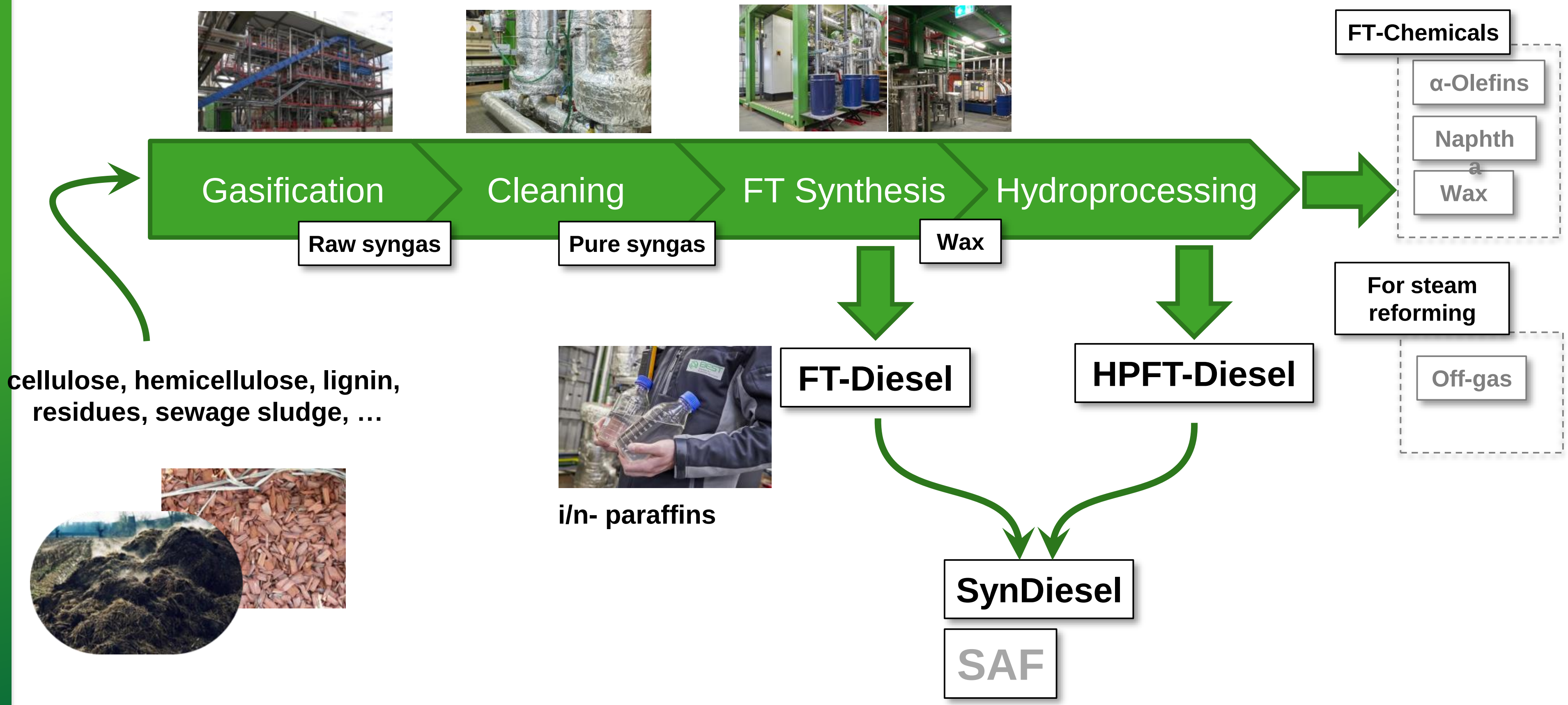
Source: R. Rauch. CHP-Plant Güssing in Handbook of Biomass Gasification Second Edition. BTG Biomass Technology Group BV, 2012.

Synthetic Production Routes

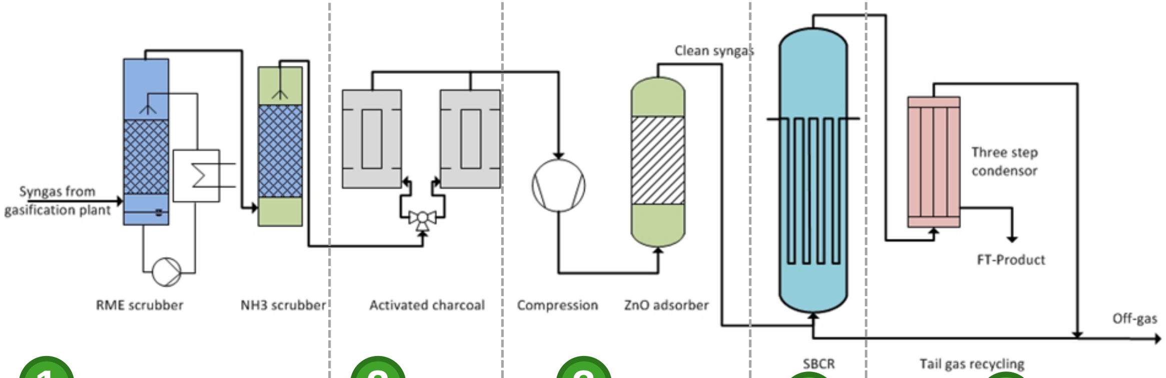


A number of different routes for synthesis of gaseous and liquid chemicals is possible starting from the generated synthesis gas.

FT Technology :: Pathway (e.g. FT-Diesel)



FT Technology :: Setup of the Process Chain



FT-Lab Scale Plant

1 Gas cleaning:

RME & Water scrubber

Removal of naphthalene, BTX and NH_3

2 Gas cleaning:

Activated carbon guards

Removal of BTX and sulphur

3 Gas cleaning & conditioning:

Compression & sulphur policy filter

Removal of sulphur

4 FTS:

Slurry bubble column reactor (SBCR)

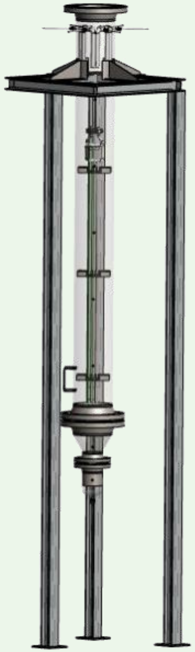
Conversion of H_2 and CO

5 FTS:

Product condensation

Separation of FT liquids & waxes

FT Technology ::
Pilot FT Plant (One-BPD)



BEST upscaled the **SBCR** FT-process from lab scale to **one barrel per day production capacity.** With this **pilot plant** valuable knowledge **on the way from the laboratory to the industrial plant** can be gained.

- Temperature range: 200-250 °C
- Pressure: 18-24 bar_a
- Production capacity: ~0.5-1BPD

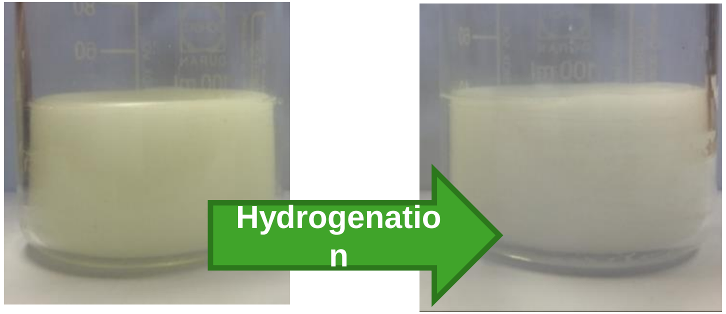
A pilot scale represents an important milestone on the way to a commercial-sized demonstration facility. A possible size for a **demo unit** would be a production capacity of **60-120** barrel per day.

FT Technology ::
Products for Chemical Industry

H&R Group · KIT Karlsruher Institut für Technologie · TU Wien · ICEBE Imagineering Nature

- **Hydrogenation of the FT wax in cooperation with H&R**
  1. Hydrogenation → Ph. Eur.
  2. Hydrogenation → FDA

1. Hydrogenation → Ph. Eur.



- ✓ **Fulfillment of the pharmacopoeia (Ph. Eur.)**
  - ✓ Check for identity and purity (IR, melting temperature, sulfate, PAH)

H. Gruber, L. Lindner, S. Arlt, A. Reichhold, R. Rauch, G. Weber, J. Trimbach, H. Hofbauer, A novel production route and process optimization of biomass-derived paraffin wax for pharmaceutical application, Journal of Cleaner Production, Volume 275, 2020, 124135, ISSN 0959-6526, ***https://doi.org/10.1016/j.jclepro.2020.124135.***

FT Technology ::
Test of Innovative FT-Reactor within H2020 Project

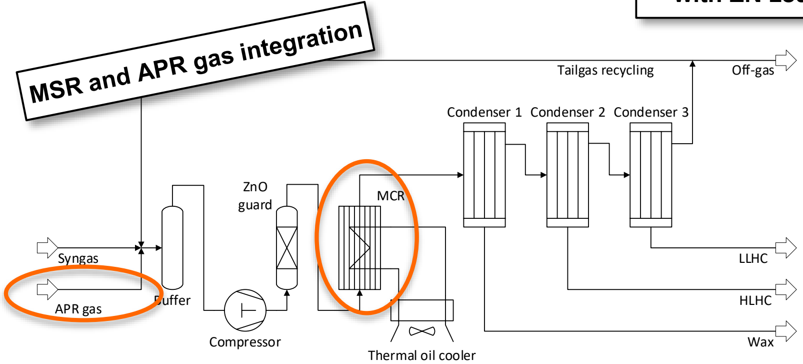
Work performed by project partners:

- ✓ Development of Aqueous Phase Reforming (APR) process for production of hydrogen from carbon-laden wastewater streams
- ✓ Development of milli structured FT reactor
- ✓ Development of innovative Co-based catalyst

Work performed by BEST:

- ✓ **Implementation of milli structured FT reactor with new catalyst system at BEST research site**
- ✓ **Construction of pilot APR-plant**
- ✓ **Test of the integrated APR-FT-process chain**

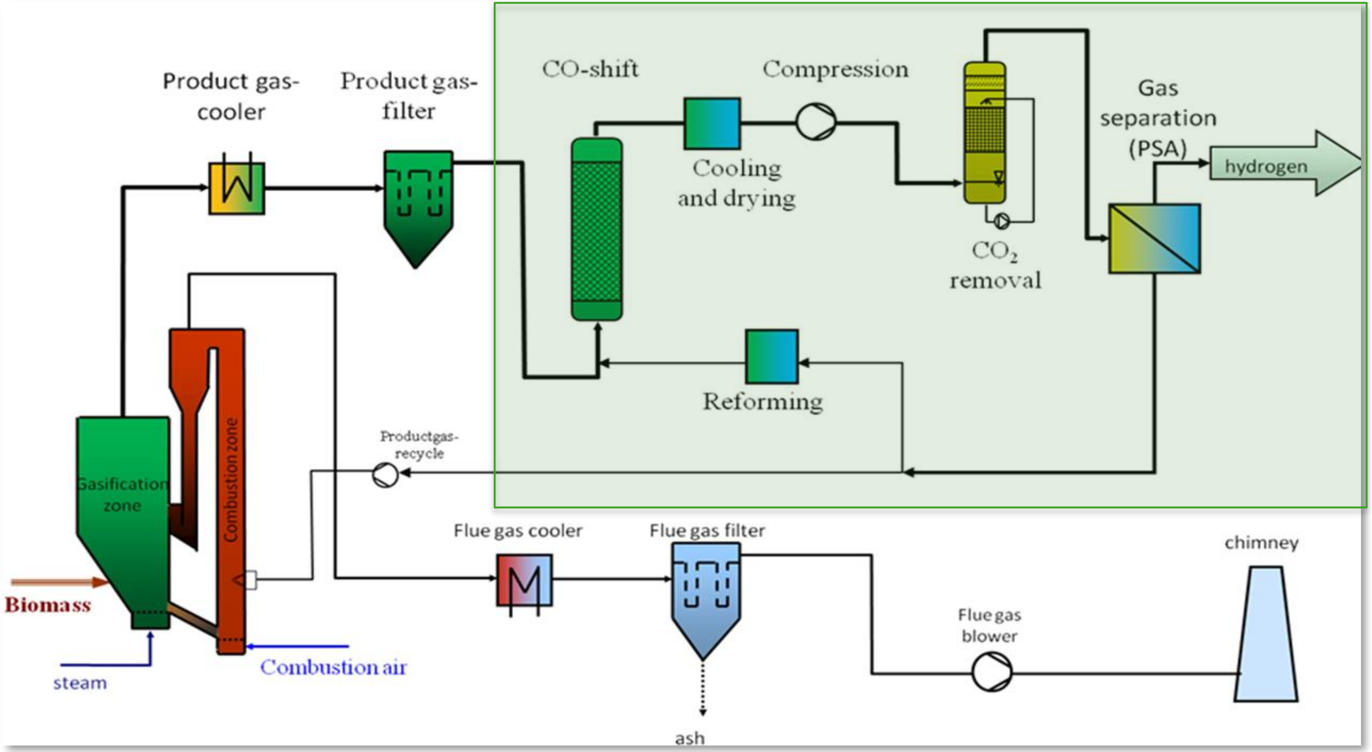
Obtained FT Diesel compliant with EN 15940



https://www.heattofuel.eu/

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 764675

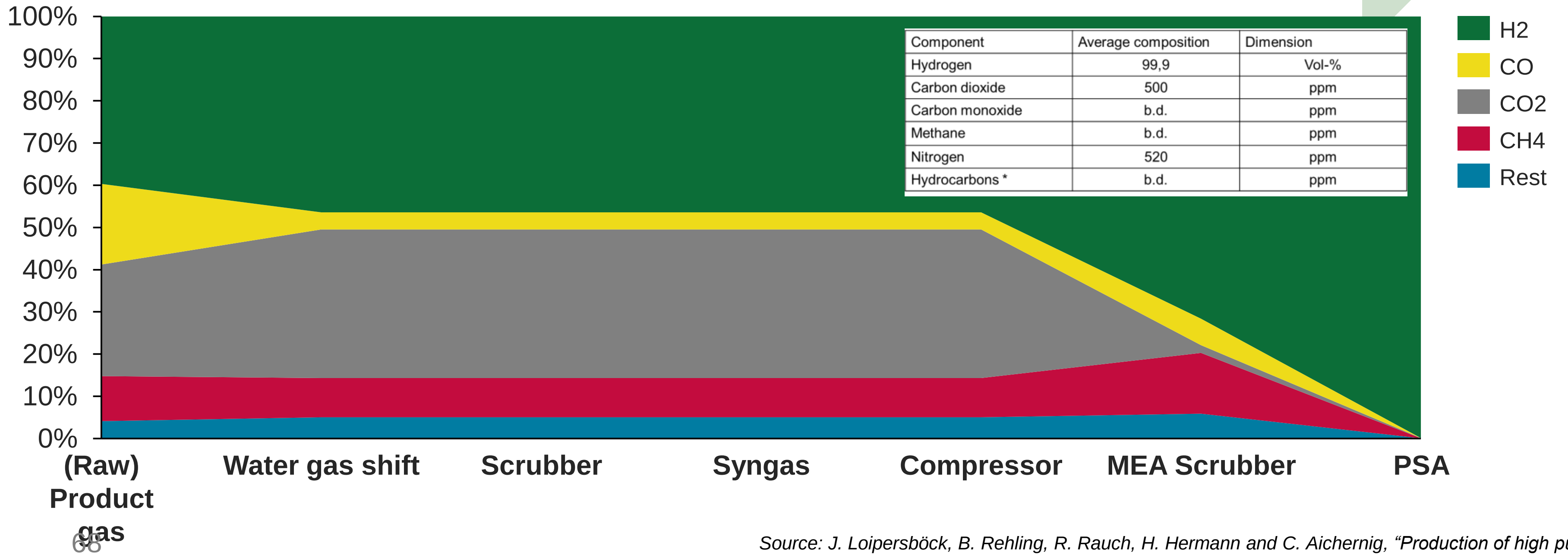
Hydrogen Production :: Setup of the Process Chain



Source: J. Loipersböck, B. Rehling, R. Rauch, H. Hermann and C. Aichernig, "Production of high purity hydrogen from biomass-derived synthesis gas using dual fluidised bed gasification technology,"

Hydrogen Production ::
Characterization of Gas Compounds along the Process Chain

vol%

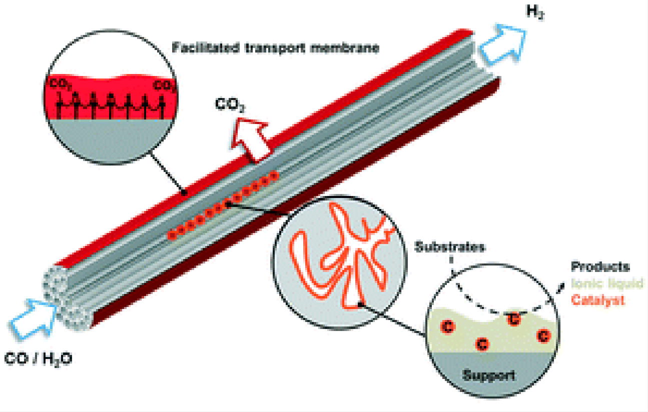


Component	Average composition	Dimension
Hydrogen	99,9	Vol-%
Carbon dioxide	500	ppm
Carbon monoxide	b.d.	ppm
Methane	b.d.	ppm
Nitrogen	520	ppm
Hydrocarbons *	b.d.	ppm

Source: J. Loipersböck, B. Rehling, R. Rauch, H. Hermann and C. Aichernig, "Production of high purity hydrogen from biomass-derived synthesis gas using dual fluidised bed gasification technology," Proceedings EUBCE, 2015

Hydrogen Production :: Improvement of Process Efficiency

Ultra-low temperature WGS reaction
=> by using Ru-complexes in a membrane reactor



Removal of CO_2 by facilitated transport

$$CO + H_2O \rightarrow CO_2 + H_2$$

"<u>Increased CO </u>conversion by shifting equilibrium towards product side"

http://www.romeo-h2020.eu/

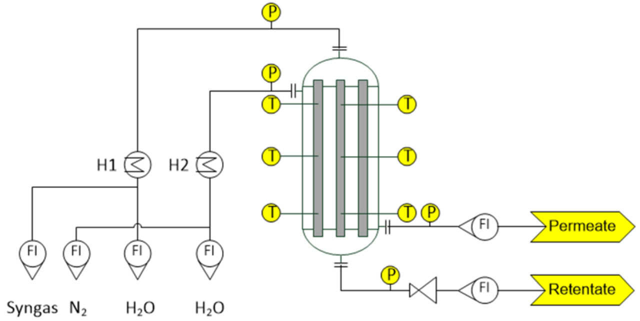
Logemann, M., Wolf, P., Loipersböck, J., Schrade, A., Wessling, M., & Haumann, M. (2021). Ultra-low temperature water–gas shift reaction catalyzed by homogeneous Ru-complexes in a membrane reactor–membrane development and proof of concept. Catalysis Science & Technology, 11(4), 1558-1570.

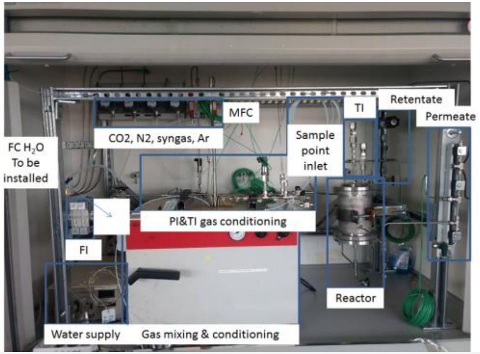
This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 680395

Hydrogen Production :: Improvement of Process Efficiency

Increase of overall energy efficiency of hydrogen production from biomass up to 65%.

Proof-of-concept: Multi-monolith membrane reactor operated with real syngas





Logemann, M., Wolf, P., Loipersböck, J., Schrade, A., Wessling, M., & Haumann, M. (2021). Ultra-low temperature water–gas shift reaction catalyzed by homogeneous Ru-complexes in a membrane reactor–membrane development and proof of concept. Catalysis Science & Technology, 11(4), 1558-1570.

http://www.romeo-h2020.eu/

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 680395

Summary

- DFB system => Nitrogen-free hydrogen-rich product gas is provided
  - Woody biomass as feedstock
- Multi-step gas cleaning (coarse and fine gas cleaning) to obtain "*synthesis gas*"
- Focus on liquid and gaseous synthesis products (e.g. FT diesel and waxes, mixed alcohols, hydrogen...)

Further technological development towards difficult fuels as feedstock for the gasification process (biogenic residues and wastes)

⚠ **Higher amount of impurities!**

Outlook

- **Focuses of R&D in the research area synthesis gas applications:**
  - Further development (new feedstocks with high amount of impurities) and improve of economics of fine gas cleaning
  - Further upscaling of slurry technology
  - R&D for the production of SAF from biogenic residues and wastes
  - Utilization of CO_2 as feedstock for FTS
  - Production of alcohols
  - Coupling of synthesis process with various syngas sources (e.g. co-SOEC)

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BEST
Bioenergy and Sustainable Technologies

Evaluation of different numerical models for the prediction of NOx emissions of small-scale biomass boilers

CEBC 2023, BEST day
Jan 18, 2023

Michael Eßl

FFG Forschung wirkt.
Bundesministerium Arbeit und Wirtschaft
Bundesministerium Klimaschutz, Umwelt, Energie, Mobilität, Innovation und Technologie
wirtschafts agentur wien
Für die Stadt Wien
Das Land Steiermark
Wirtschaft, Tourismus, Regionen, Wissenschaft und Forschung
SFG NEUES DENKEN. NEUES FÖRDERN.

Introduction

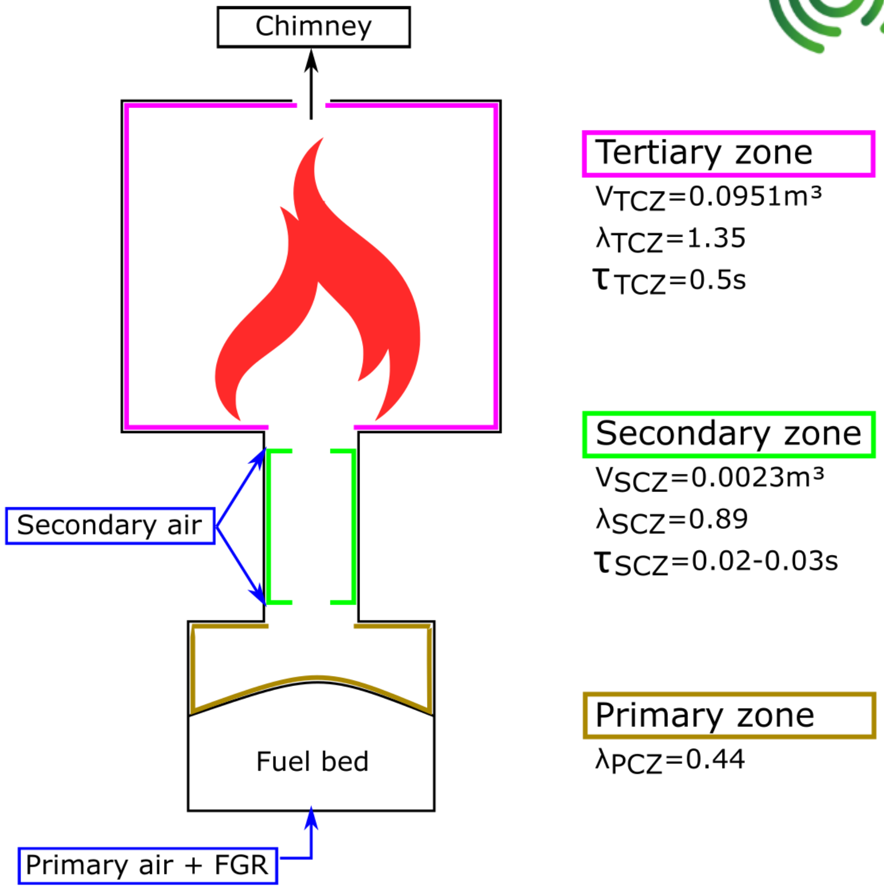
- Reduction of NOx emissions by optimization of combustion technologies
- Model Furnace: KWB Easyfire
- Numerical methods: CFD, Reactor network
- CFD is well established, but time consuming
  (especially with detailed models)
- Need for faster models to speed up the optimization process
- Derive design guidelines for new combustion concepts

[1]

[1] https://www.kwb.net/de-at/produkte/pelletheizungen/kwb-easyfire/
accessed: 10.01.2023

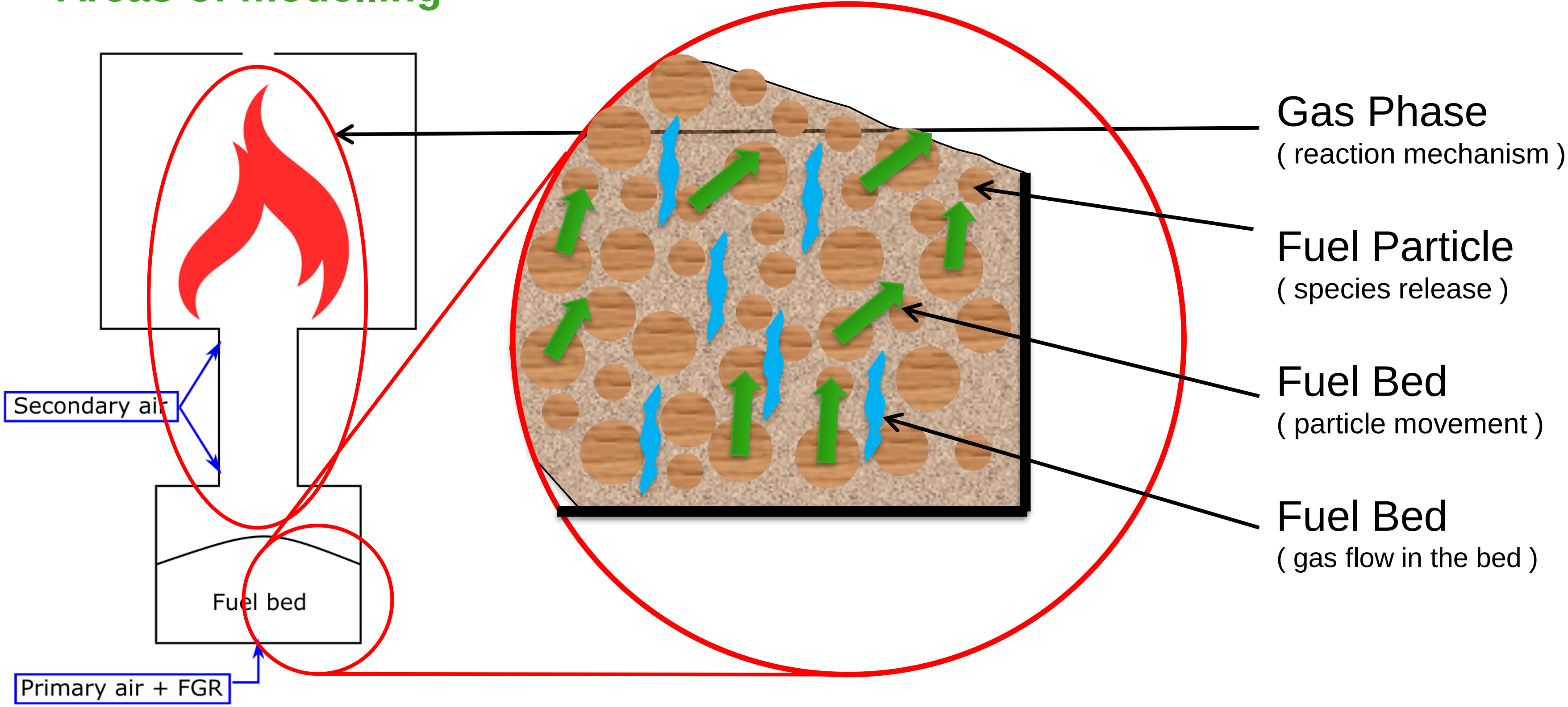
Technology / Geometry
Investigated small scale furnace

- Underfeed stoker concept
- Soft wood pellets with elevated Nitrogen content
- Primary air with flue gas recirculation
- Secondary air injection via two rows of nozzles → creating a separate reduction zone between rows



CFD

Areas of modelling



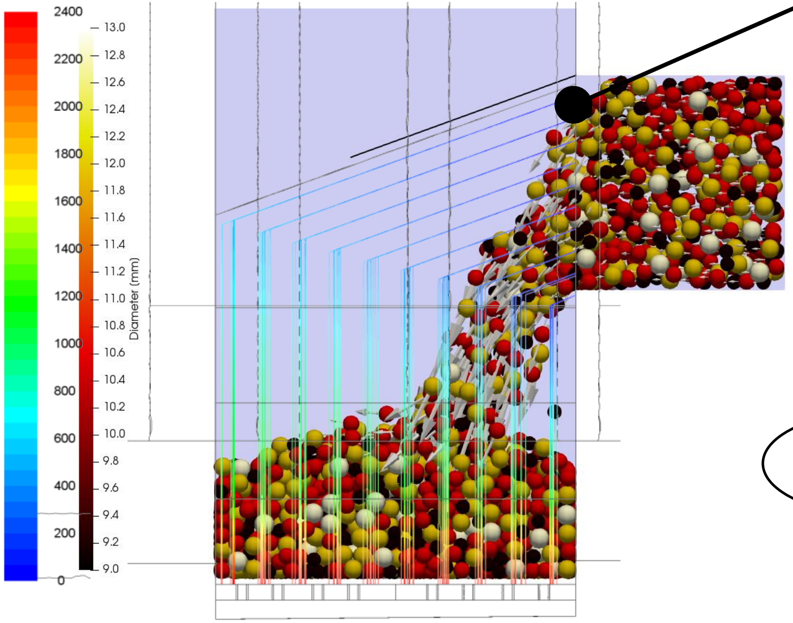
CFD

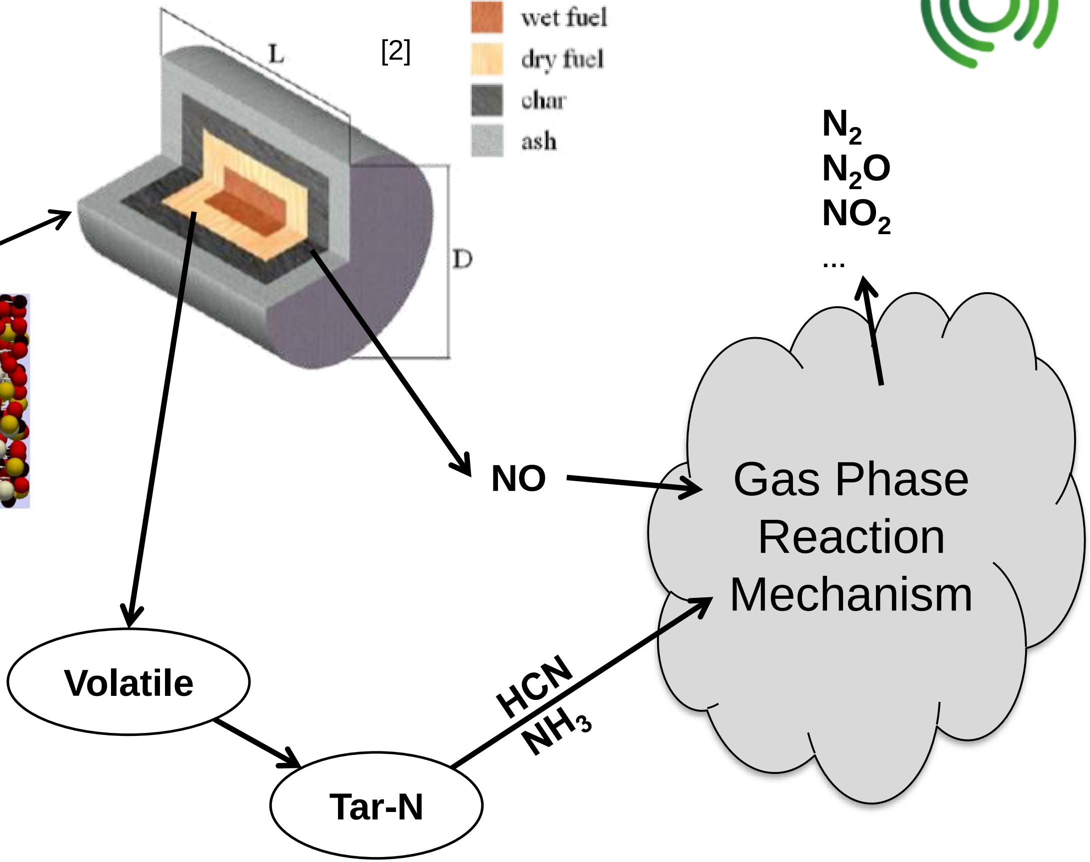
Simulation procedure

Particle Model – species release

Discrete Element Simulations

Residence time distribution [s]



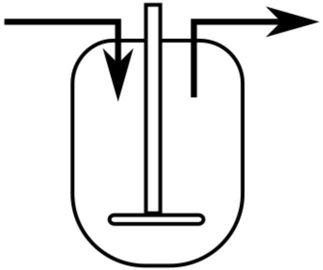


[2] Mehrabian, R. et.al; A CFD model for thermal conversion of thermally thick biomass particles, Fuel Processing Technology, 2012, 95, 96-108

Reactor network

Idealised reactor models

Continuously Stirred Tank (CSTR)



- Uniformly (perfectly) mixed
- Same composition inside reactor and at the exit
- Mixing of intermediate products with fresh input stream

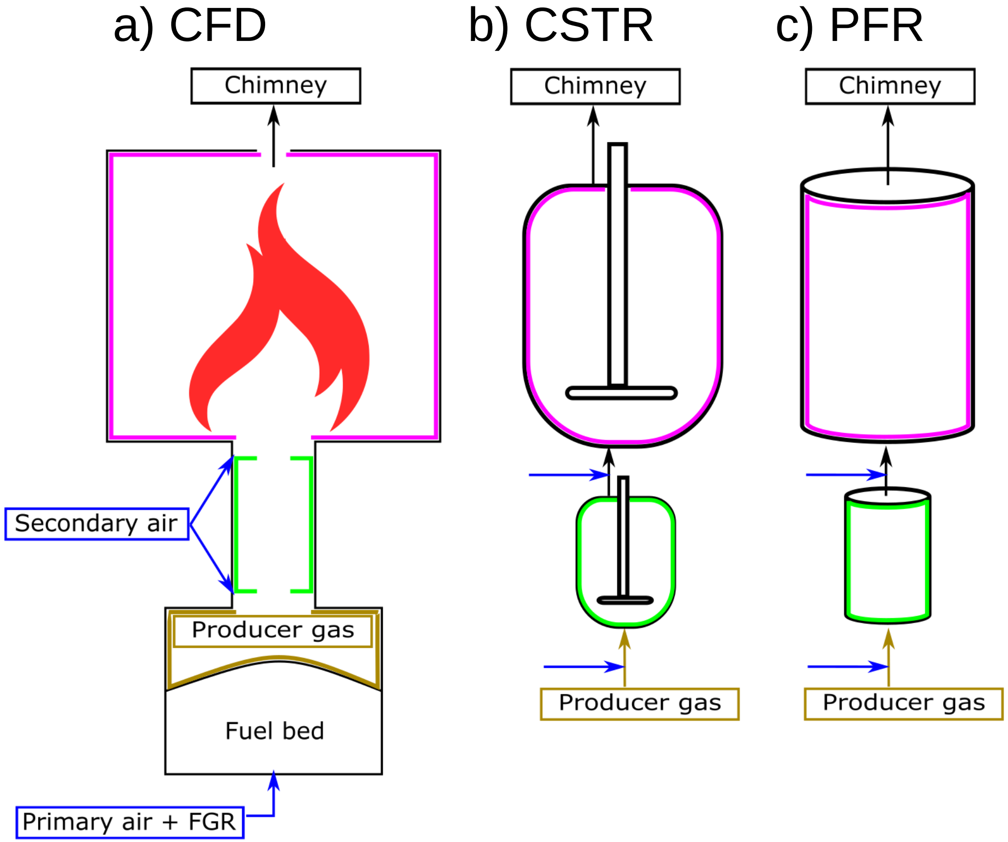
Plug Flow (PFR)

- Perfectly mixed in radial direction
- No mixing in axial direction
- No mixing of intermediate products
- Composition changes in axial direction

Reactor network

Network configuration

- Extract producer gas composition from CFD simulation
- Represent zones with ideal reactors (CSTR and PFR)
  - Reduction zone between rows of nozzles
  - Combustion chamber
- Isothermal conditions



Results

Comparison of numerical models

- CSTR and PFR mark the influence of mixing on the NO_x emissions
- CFD is partially mixed
- Comparison with experimental data are in good agreement
- Simulation time (estimation)
  - CFD: ~2-3 weeks
  - Reactor network: ~1-10 minutes
- Time per case study (estimation)
  - CFD: ~3-4 weeks
  - Reactor network: ~1-3 days

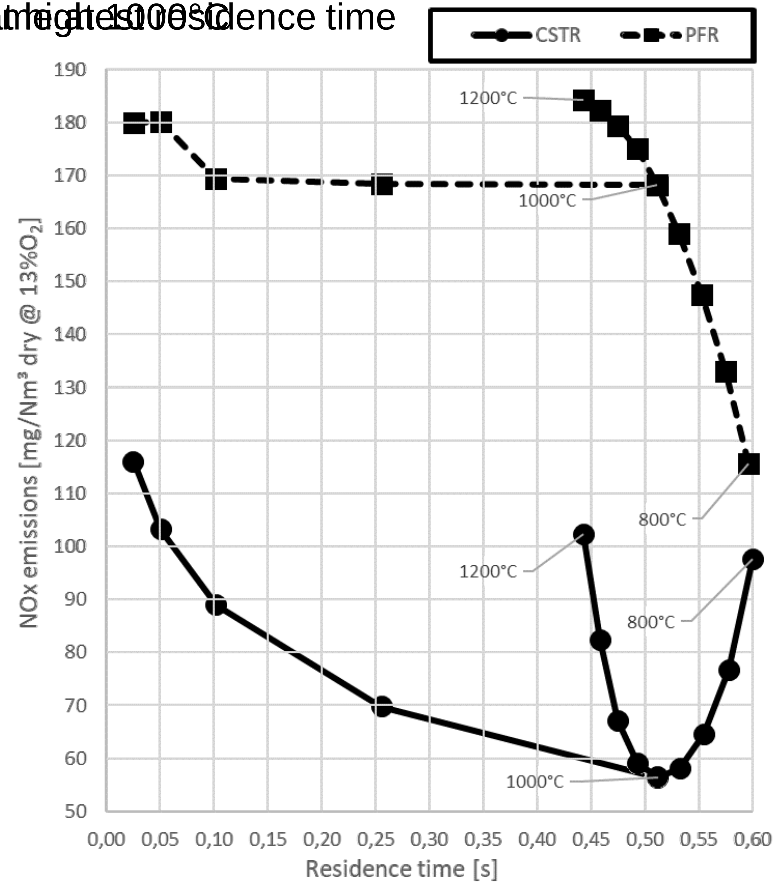
Comparison of models and measurement [mg/Nm³ dry @ 13%O_2]

	CSTR	CFD	PFR	Exp.
SCZ	144	264	302	-
TCZ	118	165	180	153

CSTR … Continuously Stirred Tank Reactor
PFR… Plug Flow Reactor
CFD… Results from CFD simulation
Exp. … Measured values

Results
Parameter study

- Variation of volume and temperature of reduction zone
- Increasing volume
  →Increasing residence time
  →Increasing furnace dimensions
  →Increasing cost
- Find the optimal value for NOx reduction and furnace dimensions
- Possible further variations:
  - Producer gas composition
  - Air to fuel equivalence ratio (λ)



Summary / Outlook

- Reactor network simulations are well suited for predicting volume, λ, temperatures, residence time, and mixing.
  → Basic engineering
  - No fuel bed model integrated, must be determined externally
    (CFD, measurement, external fuel bed model)
- CFD simulations are well suited for detailed evaluation of geometry variations, fuel bed conditions and heat flows
  → Detail engineering
- At BEST both methods will be applied to estimate NOx reduction potential of biomass combustion concepts on one hand and to get detailed insight and provide suggestions for optimization measures

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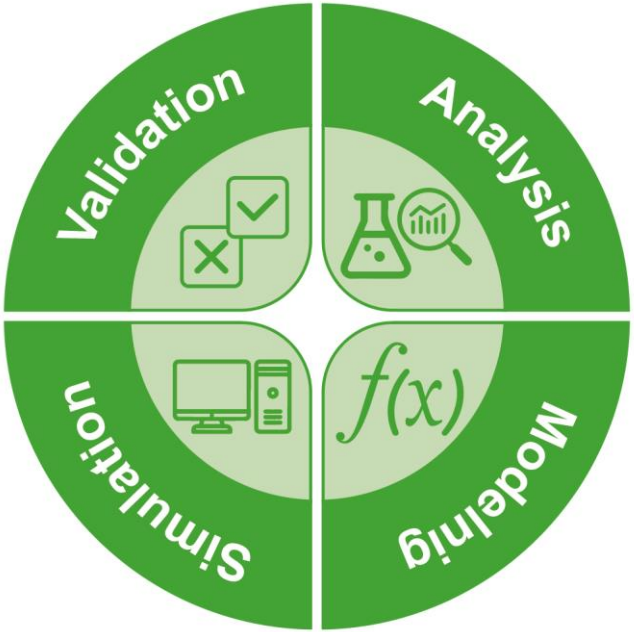

BEST
Bioenergy and Sustainable Technologies

Digitalization as the basis for the efficient and flexible operation of renewable energy technologies

CEBC 2023, BEST day
Jan 18, 2023

Markus Gölles

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Bundesministerium Arbeit und Wirtschaft
Bundesministerium Klimaschutz, Umwelt, Energie, Mobilität, Innovation und Technologie
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Für die Stadt Wien
Das Land Steiermark
Wirtschaft, Tourismus, Regionen, Wissenschaft und Forschung
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What exactly is meant by DIGITALIZATION?

Wikipedia

- conversion of analog values to digital
- processing / storage in digital system
- analog information initially available ... converted to a digital signal **consisting only of discrete values**.
- ... data can be processed by information technology, ...

Interpretation for renewable energy systems

1. making information digitally available
2. automated use of information

- “all” tasks can be automated
  → faster, more efficient / reliable …
  → many tasks become manageable for the first time

Need for increased digitalization for the transition to a sustainable energy and resource system

- **Sustainable energy and resource supply**
  - different technologies need to work together very flexibly
  - many hurdles still must be overcome on this path (technical, legal, …)
  - very limited time and personnel resources

- **Digitalization**
  - allows a significant increase in the degree of automation
  - standardized (more efficient) processes, more sophisticated methods, …

- **Currently many systems still lack a high degree of digitalization (min. CAPEX)**

- **With increased complexity, the need for flexibility, … more powerful tools and methods (and thus increased digitalization) simply will be necessary**

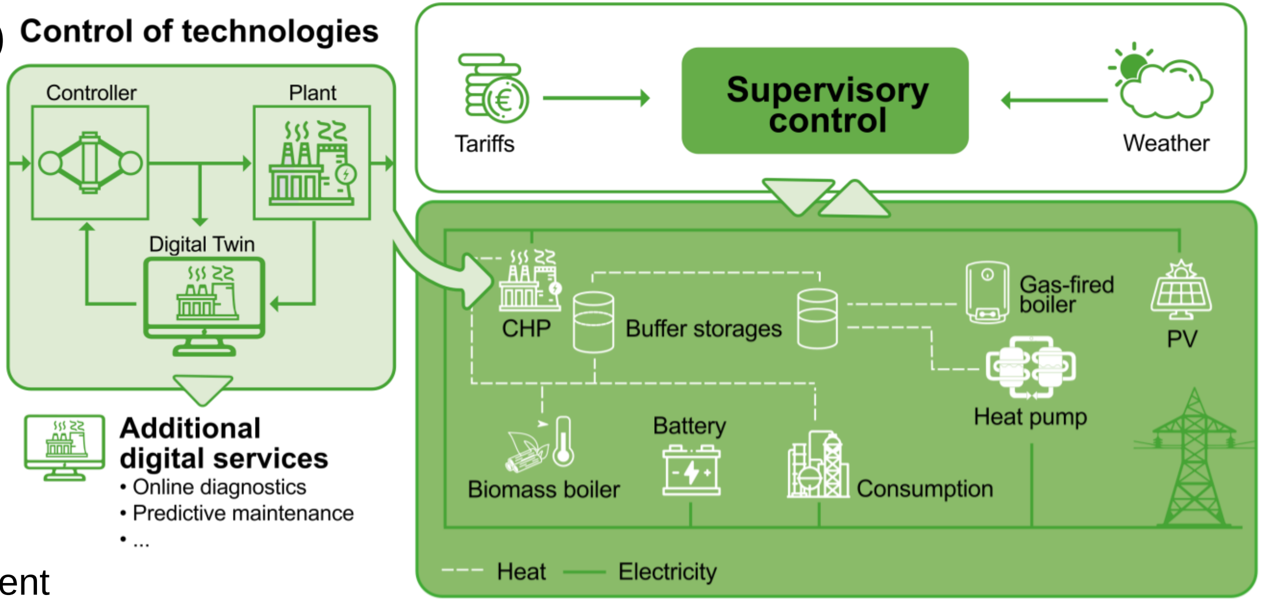
Possibilities evolving from increased digitalization for operation of renewable energy and resource systems

Advanced control concepts for different technologies

- highest efficiencies
- flexibility (modulation, fuels)

Optimal interaction of different technologies

considering available information (history, weatherforecast, …)



Various new digital services

simplifying the operational management

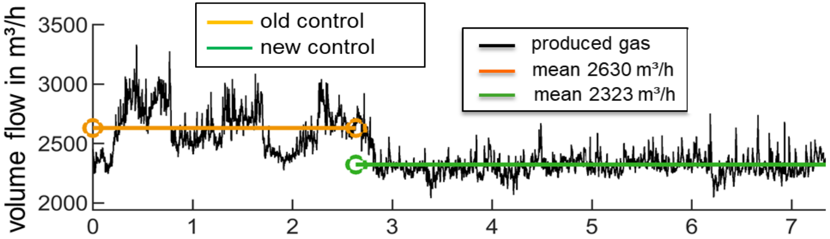
Advanced control concepts (technology level)

- **Advanced (model-based) control methods needed** to achieve
  - highest efficiencies in all operating points
  - high flexibility in terms of modulation capability and input streams used
- **Digitalization provides basis**
  - data necessary for model parametrization
  - possibility for systematic control design
- **Wide use of developed methods happens slowly**
  - comparatively high CAPEX due to high costs for basic digitalization
  - required expertise / effort for implementation needs to be further decreased
  - awareness of potential for improvement through control enhancements too low

Advanced control concepts (technology level)

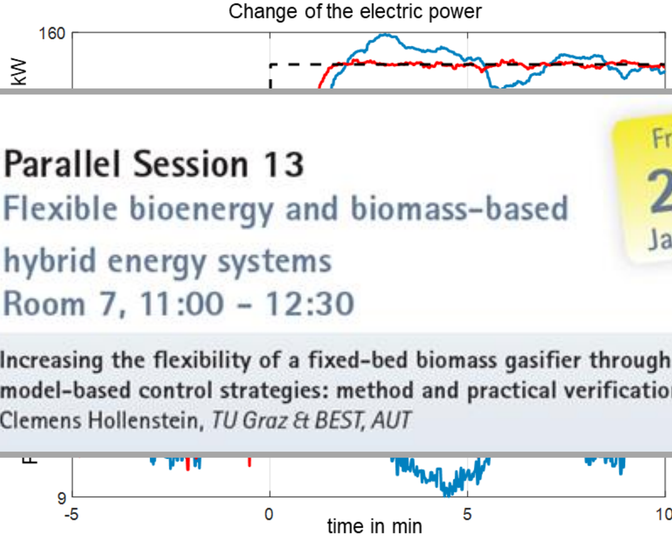
Dual fluidized bed gasifier

HGA Senden/Ulm
(Germany, 5 MW_{el})



same electricity production with 7% less fuel

Fixed-bed gasifier



Parallel Session 13
Flexible bioenergy and biomass-based hybrid energy systems
Room 7, 11:00 – 12:30

Friday 20. January

Increasing the flexibility of a fixed-bed biomass gasifier through model-based control strategies: method and practical verification
Clemens Hollenstein, *TU Graz & BEST, AUT*

increased modulation capability and stability

Digitalization supports application of advanced (model-based) control methods

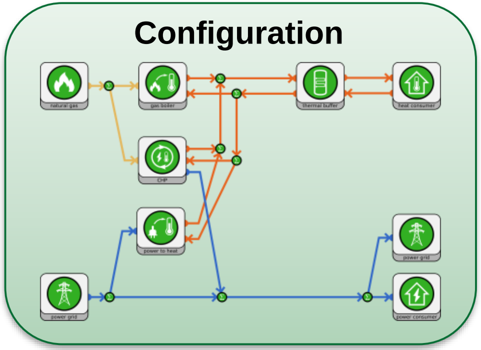
Optimal interaction on system level

- **Increased complexity / sector coupling**
  - need for overarching control strategies easily adjustable
  - Plug & Play (limited personnel resources, need for low CAPEX)
  - difficult to develop control strategies only with expert knowledge

- **Increased digitalization offers new possibility**
  - considering weather forecasts, historical data, …
  - increase in degree of automation in generation of the actual control

- **Software frameworks for an efficient (highly automated) provision of control strategies for different configurations required**

Modular framework for the optimization-based, predictive supervisory control




```
"type": "EmSimpleHeatProducer",
"name": "c64a8fd5-ec0e-4a5c-abb1-39e90d8e8cbf",
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  "Minimal Output Percent": "40",
  "Nominal Output Power": "8",
  "Boiler Status": "simplified",
  "Nominal Return Temperature": "30",
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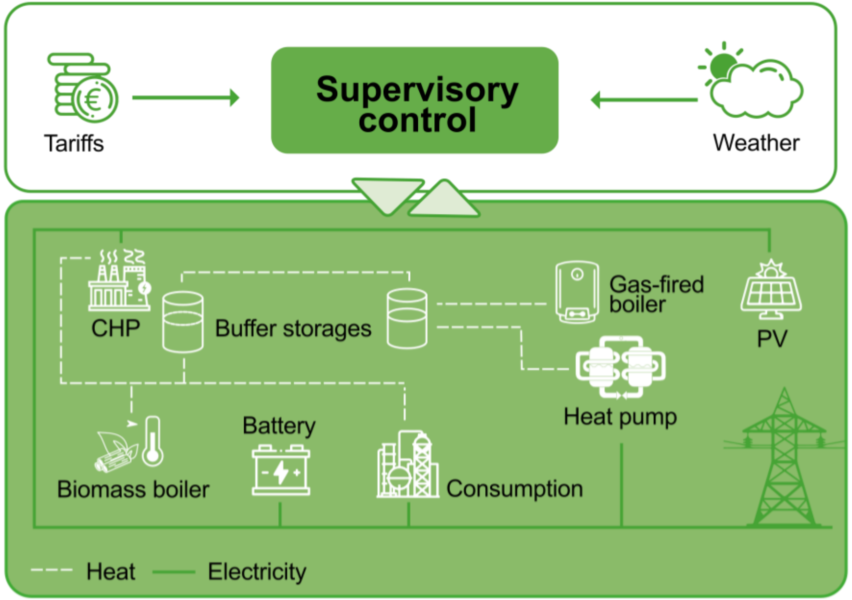

Modular framework for the optimization-based, predictive supervisory control

- **Modular design allows flexible and efficient configuration**

- **Consideration of many different**
  - … r therm … …)
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  - …)
  - … , …)

BEST-Day: Sustainable biorefineries and digitalization, **Room 6, 13:30 – 17:00**

Wednesday
18.
January

Smart Control for Coupled District Heating Networks
Valentin Kaisermayer, *Automation & Control*

Parallel Session 13
Flexible bioenergy and biomass-based hybrid energy systems
Room 7, 11:00 – 12:30

Friday
20.
January

Predictive control of biomass and biogas-based CHPs at the intersection between the electricity grid and heating networks – Improving electricity market participation through optimization and demand side management
Daniel Muschick, *BEST, AUT*

- **Several successful implementations & first commercial product**
  - buildings (single family houses, large office buildings), heating girds

Typical improvement (efficiency, CO_2 reduction, …) achievable: ~ 5-10 %

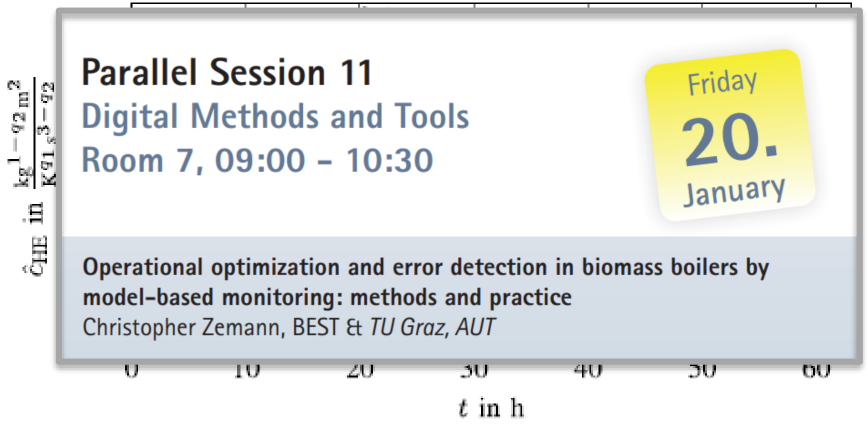
Potential for various new digital services

Availability of data, models, … creates countless possibilities

- Automation of monitoring and supervision
- Automatic fault detection
- Predictive maintenance
- In the development process (SIL / HIL) or as plant simulator

Examples for additional digital services

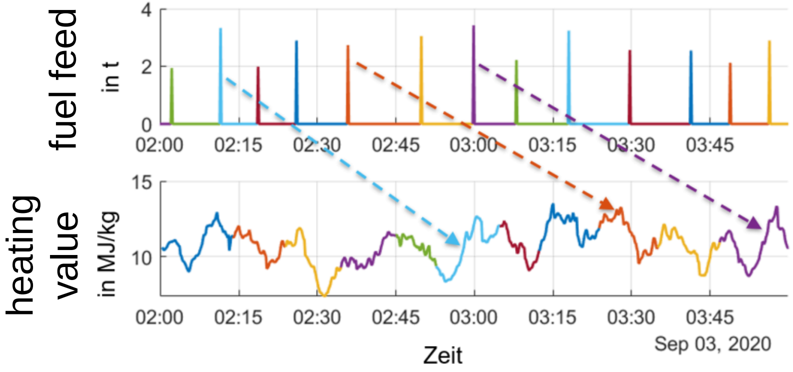
Heat exchanger fouling



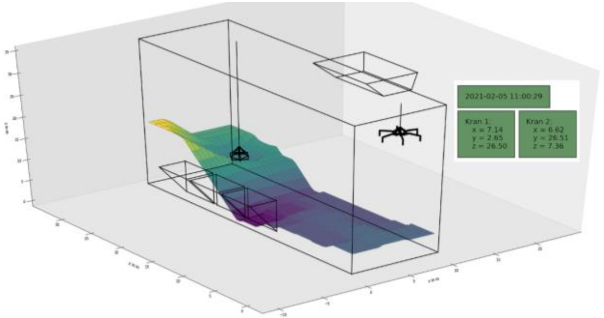
prediction of future efficiency decrease

→ maintenance

Digital Twin of Waste Incinerator



allows for homogenization of the fuel feed



New digital services can simplify the operational management

Conclusion

- **Many new possibilities by digitalization**
  - efficiency increase, more flexible operation, simpler operational management, …
- **Necessary to achieve a sustainable energy and resource system**
  - efficiency losses of up to 10% need to be avoided
  - less (and less qualified) personnel available for operation / maintenance / ...
- **Specific CAPEX is reduced by addressing several measures**
  - many steps (basic digitalization, automation) only to be carried out once

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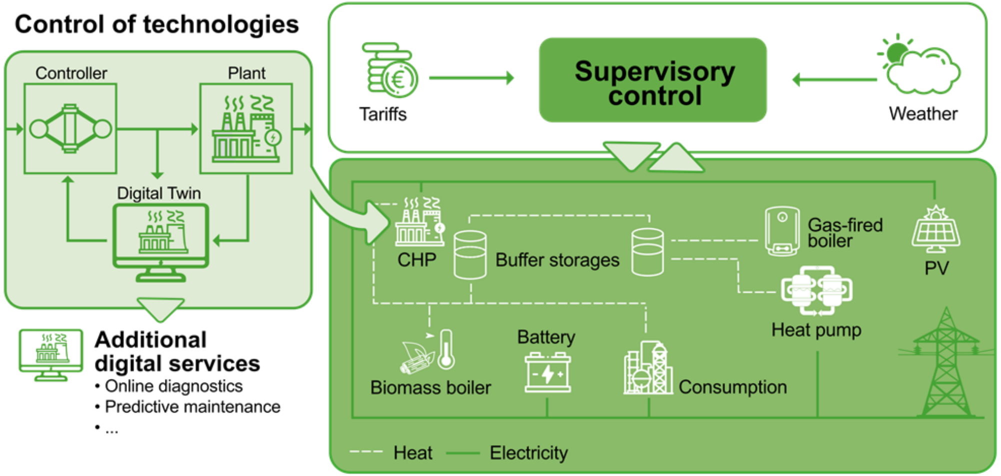

Smart Control of Interconnected District Heating (DH) Networks

CEBC 2023, BEST day
Jan 18, 2023

Valentin Kaisermayer, Daniel Muschick,
Markus Gölles, Martin Horn

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Wirtschaft, Tourismus, Regionen, Wissenschaft und Forschung
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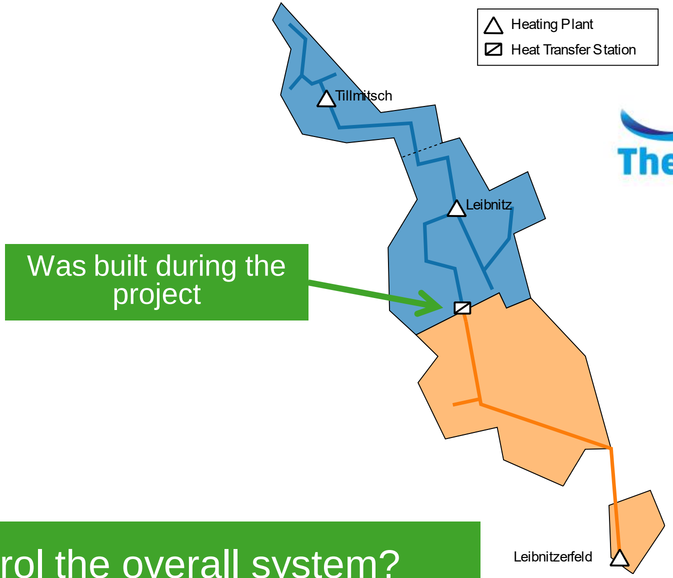
With growing DH networks, the opportunity for interconnection arises

- **Exploit synergies**
  - Different production technologies, costs, thermal energy storage (TES) sizes, waste heat potential, renewable production…
- **(Bi)directional heat transfer**
- **Overall Goal**
  - Minimization of CO_2 emissions/costs

- **Example** – Leibnitz[1]



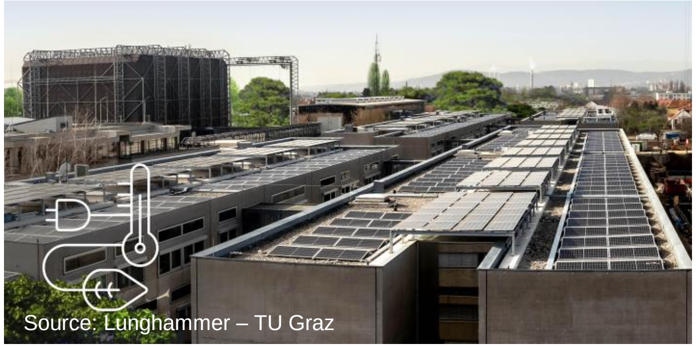
How to control the overall system?
Especially, the import and export of heat?

1 https://greenenergylab.at/projects/100-renewable-district-heating-leibnitz/

Energy management systems (EMSs) are versatile supervisory controllers for energy systems

- What do we mean by EMS?
  - **Supervisory controller** coordinating producers, storage and consumers in an energy network
  - **Optimization-based** Finds the best operating strategy by solving an optimization problem
  - **Predictive** Takes future demands, yields and prices into account
- **Many applications**
  - Building energy management
  - Control of district heating (DH) networks
  - ...

Are there any open challenges for the use of EMS in interconnected DH networks?


Source: Lunghammer – TU Graz


Source: thermaflex.greenenergylab.at

Open challenges for the use of EMS in interconnected DH networks

- **Representing thermal systems**
  Temperature levels are important

- **Dealing with low-level controllers**
  EMS is often only added during a retrofit
  and only able to control a subset of the production units

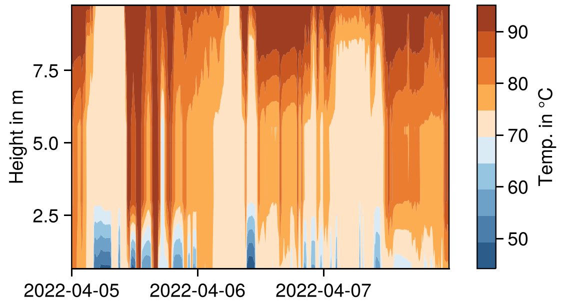
- **Handling multi-owner settings**
  Different owners might have different goals

Not part of this talk

Representation of thermal systems in optimization-based EMS

Typical energy-based models are not good enough for thermal systems

- **Thermal energy storage (TES)**
  - The energy-based models would only allow for two layers (hot and cold)
  - In reality, no ideal stratification between a hot and cold layer



- **Low-level controllers**
  - Operate on specific temp. levels of the TES
- **Consumption and production on different temperature levels**
  - e.g. solar, DHW, floor heating and boiler
- **Solution: Non-linear optimization?**
  - Problematic for real-time applications; we like mixed-integer linear programming (MILP)

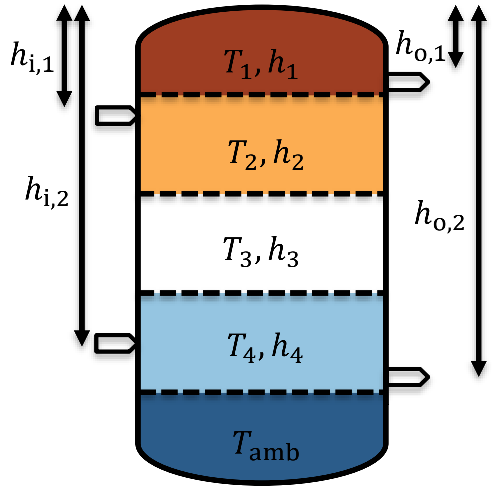
Can we do better?

A multi-layer approach for thermal systems in MILP-based EMS

- **Idea:**[1] Approximation of a massflow at varying temperature with multiple massflows at constant temperatures
- Can be applied to general thermal systems
  heat pumps, solar thermal,…

Allows us to handle all the problems that usually occur with energy-based models

- **Example** - TES



1 Muschick, D., Zlabinger, S., Moser, A., Lichtenegger, K., & Gölles, M. (2022). A multi-layer model of stratified thermal storage for MILP-based energy management systems. *Applied Energy*, *314*, 118890. https://doi.org/10.1016/j.apenergy.2022.118890

Handling of low-level controllers in optimization-based EMS

EMS are often added during a retrofit – must handle existing controllers

- EMS is often only added during a **retrofit**
- Need to **gain trust** first
- EMS may at first be only allowed to...
  - provide **optimal setpoints** for low-level controllers
  - control a **subset of the production units**

- Low-level controllers are very often “simple” but **highly non-linear**
  - Two-point controller, PI with anti-windup, IF-THEN-ELSE logic

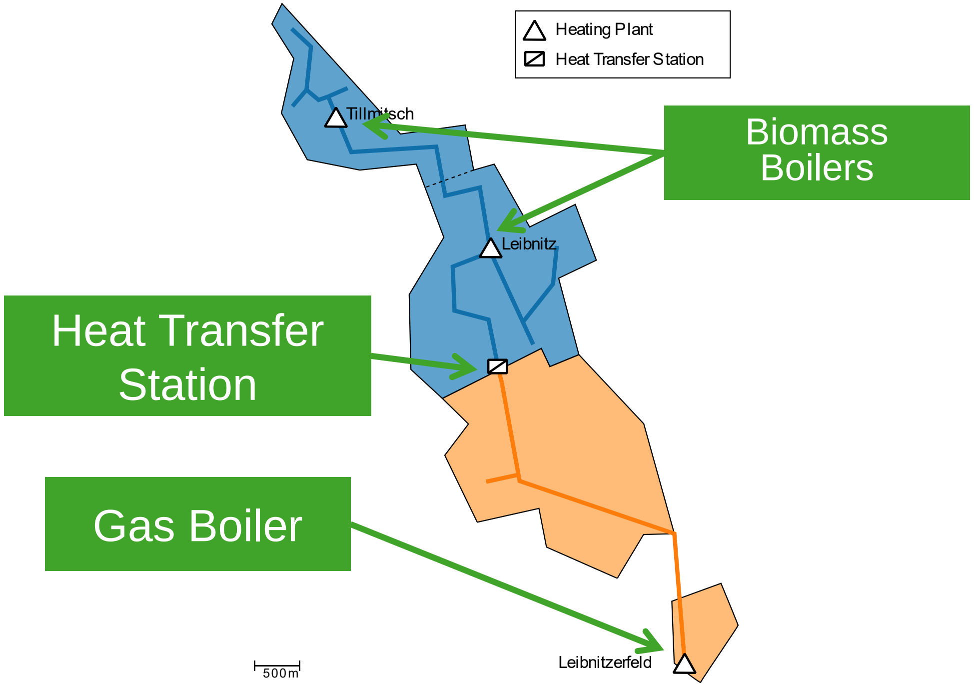
- **Solution**: Approximate via mixed logical-dynamical systems[1]

1 Bemporad, A., & Morari, M. (1999). Control of systems integrating logic, dynamics, and constraints. *Automatica*, *35*(3), 407–427. https://doi.org/10.1016/S0005-1098(98)00178-2

For Leibnitz the EMS was at first only allowed to control the heat transfer station

- EMS was **not allowed to control the boilers directly**
  Still controlled via low-level controllers

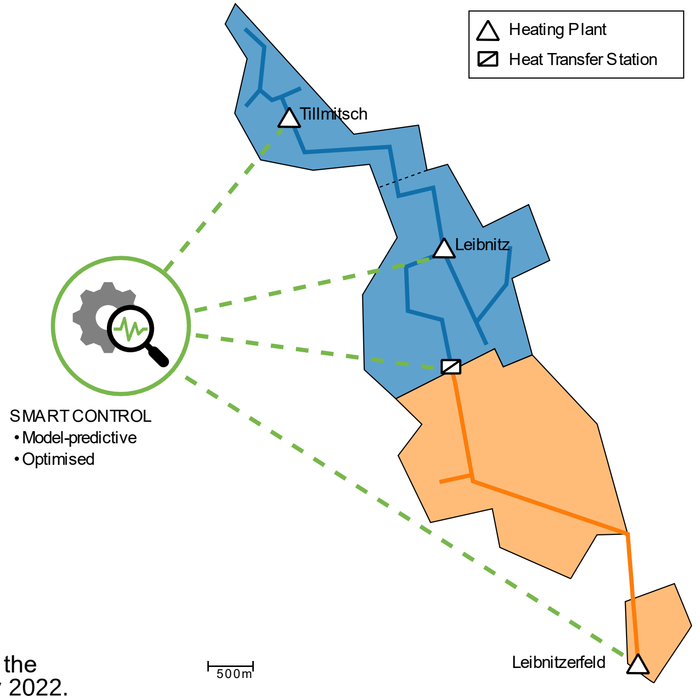
- **Indirectly influence** via the heat transfer



Real Operation

How was the real-time EMS implemented?

- In Julia, running on a server from BEST GmbH
- Computes **optimal schedules** every 15min with a **72h planning horizon**
- Communication to heating centres via REST-API
  - Local **fall-back strategy** if communication fails
- **Running since April 2021**[1]



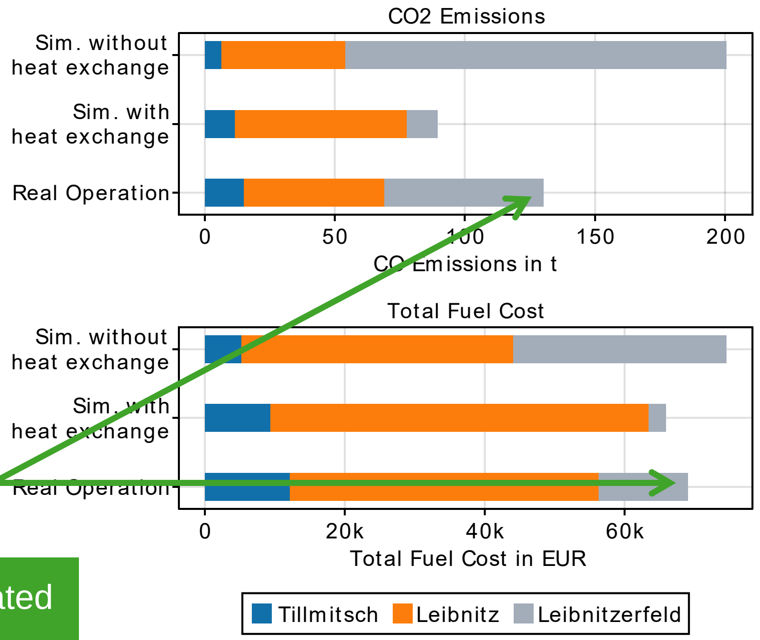
1 V. Kaisermayer *et al.*, “Smart control of interconnected district heating networks on the example of ‘100% Renewable District Heating Leibnitz,’” *Smart Energy*, vol. 6, May 2022.

A simulation study helps for estimating the potential and serves as a best-case

Scenarios

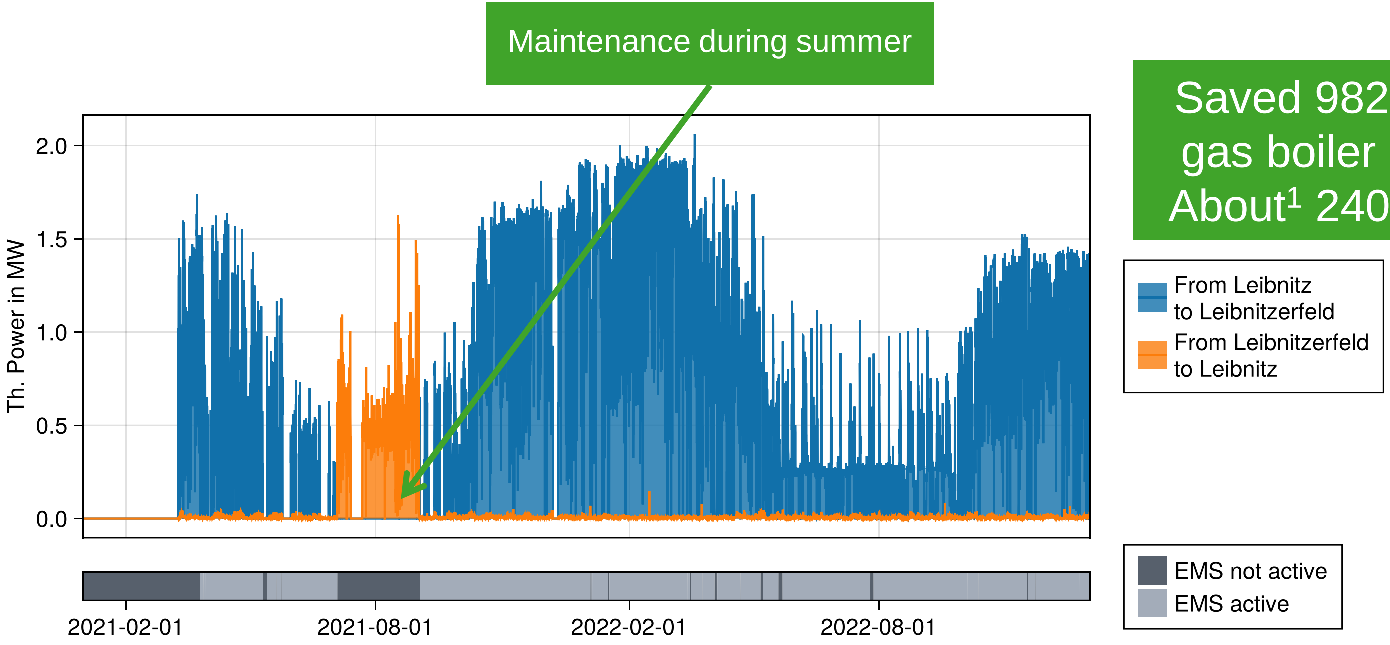
- Base case without heat transfer station
- With the new bidirectional heat transfer station
- Real operation

35% reduction in CO_2 emissions 7% fuel cost reduction during 1 month (April 2021)



Real operation was not as good as estimated – the EMS did not have full control

The EMS and heat transfer station considerably decreased the overall CO2-emissions



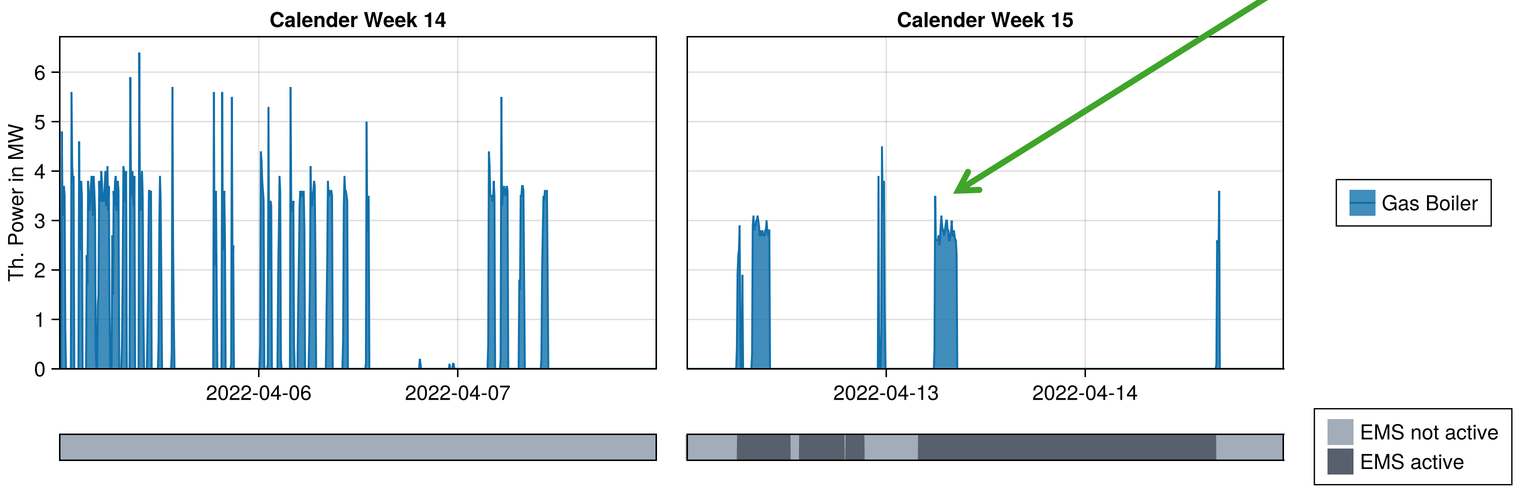
Saved 9823 MWh of gas boiler operation
About[1] 2400 t of CO_2

1 Assumption 0,201 tCO_2/MWh @ 80% efficiency

The EMS was able to reduce the gas boiler operation and improve its operating conditions

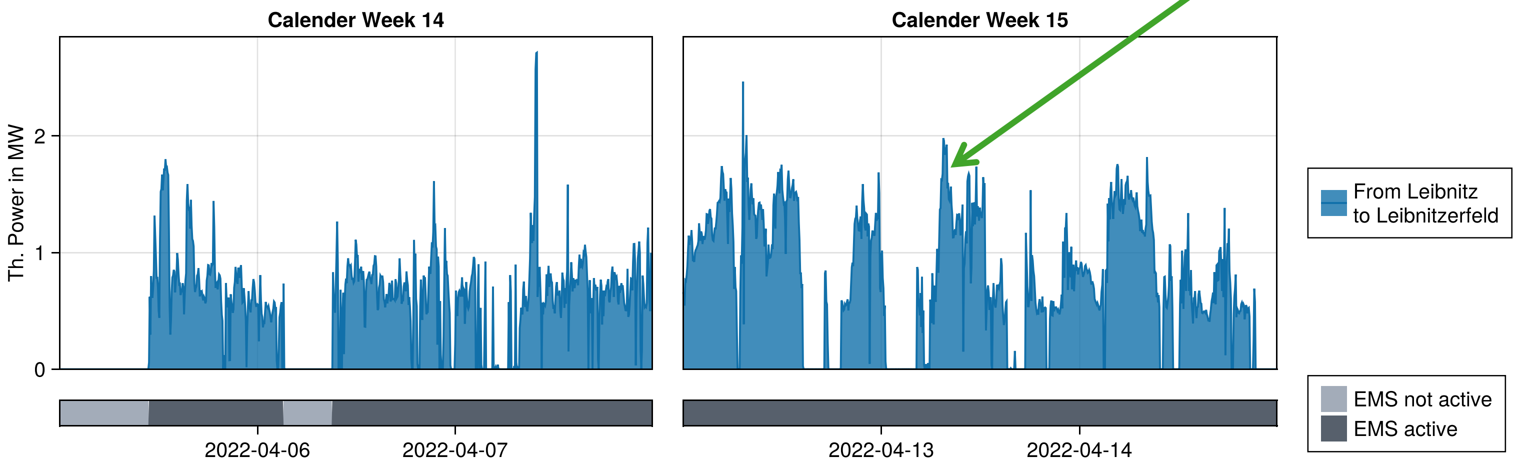
- During calendar week 15 the EMS was given full control

Reduced gas boiler operation by 70%
Better operating conditions:
(longer run time, lower power level)



Giving the EMS full control improves the operating conditions

Better operation of the heat transfer station (closer to capacity limit)



Main take-away – an EMS is well suited for a complex energy system like interconnected DH networks

- **An optimization-based energy management system** (EMS) is well suited for controlling interconnected DH networks
  - Is able to **improve operating conditions** and **minimize CO_2-emissions/costs**

- **Real-time EMS demonstrated**, handling…
  - Thermal systems accurately
  - Low-level controllers

- **Outlook**
  - What about **coupling with other sectors**, e.g. electricity?
  - Incorporation of thermal **demand side management**?

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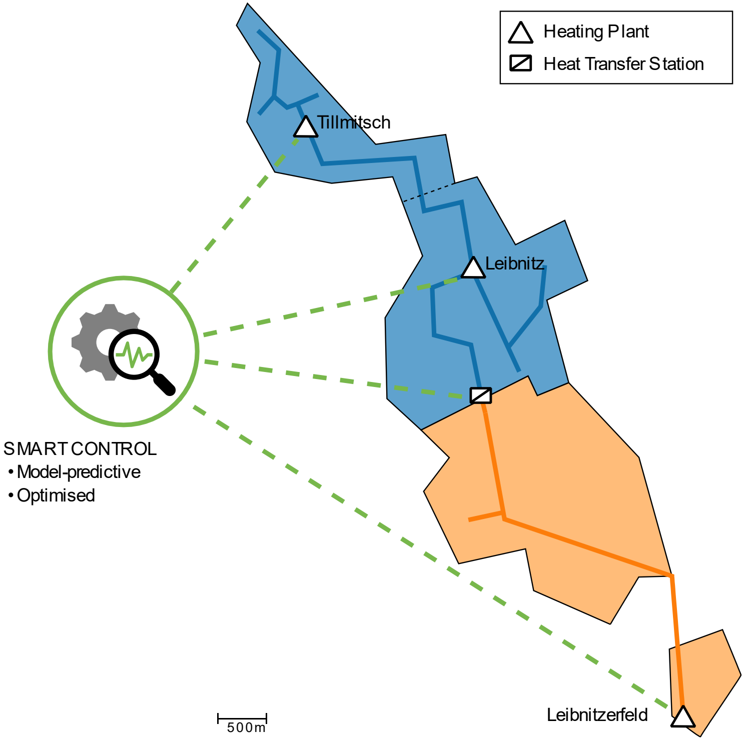


Integrated energy solutions for a decentral energy future – challenges and solutions

CEBC 2023, BEST day
Jan 18, 2023

Smart- and Microgrids Team:

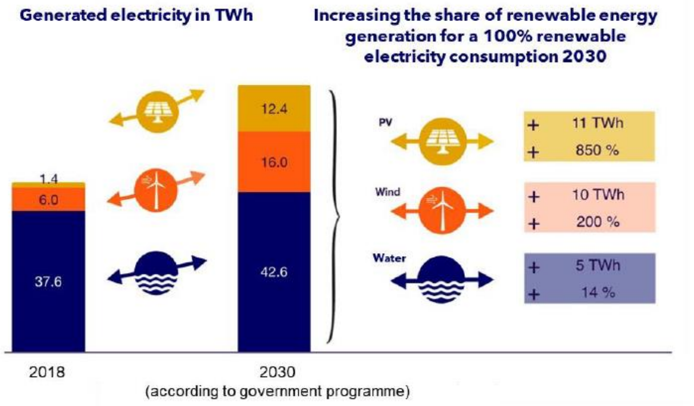
Stefan **A**igenbauer, Armin **C**osic, Nikolaus **H**ouben, **Pascal Liedtke**, Christine **M**air, Christian **O**berbauer, Michael **S**tadler, Rita **S**turmlechner

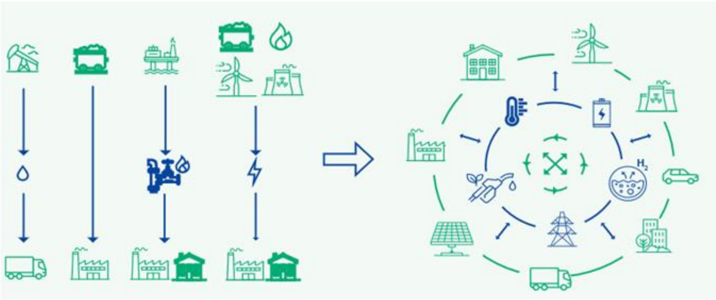
Challenges in Energy Supply

- Strong (fossil) **dependencies** in **energy supply** → **Current energy crisis makes problems visible** !

- **National expansion targets** for renewables by 2030

- **Energy industry in transition** → **From centralized to decentralized energy systems** :
  - **Previously:** Simple central power plants, great dependence on the energy supplier
  - **Now**: Affordable, decentralized energy technologies (PV, wind, storage); Emergence of local energy systems (RECs); High complexity → Holistic planning necessary!





Quelle: https://ec.europa.eu/commission/presscorner/detail/en/fs_20_1295

Smart- & Microgrids as a solution

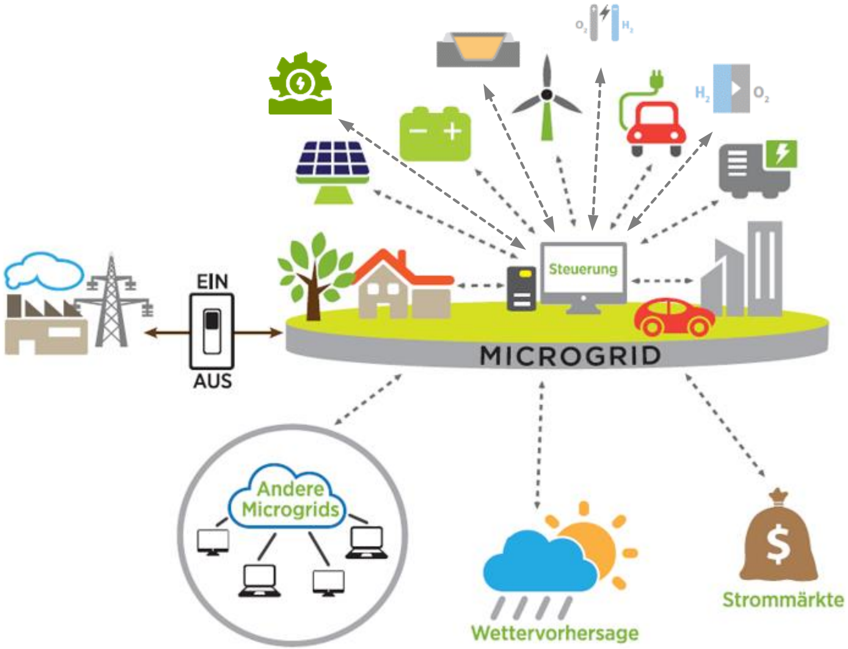
Local energy grids for electricity, heating/cooling

Energy system transformation:

- Microgrids
- Decentral energy systems
- Regional/local energy communities

Local solutions:

- High **efficiency** → Generation & demand are close to each other
- Excellent **integration** of volatile renewables → **Energy management !**
- **Reduction** of energy costs & emissions
- Increased **supply security**
- Increasing regional value creation and **sustainability**



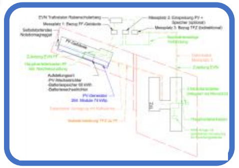
Holistic solutions for a decentral energy future

- **BEST** established **first real-life microgrid research test lab** to map their **holistic energy concept** for decentralized energy grids in Austria**:**

Planning

OPT
EN
GRID

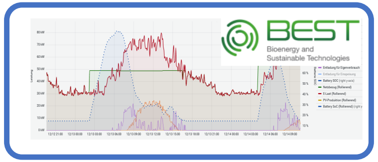
Conceptual Planning



Detailed Planning & Communication Set up

Real-time Operation

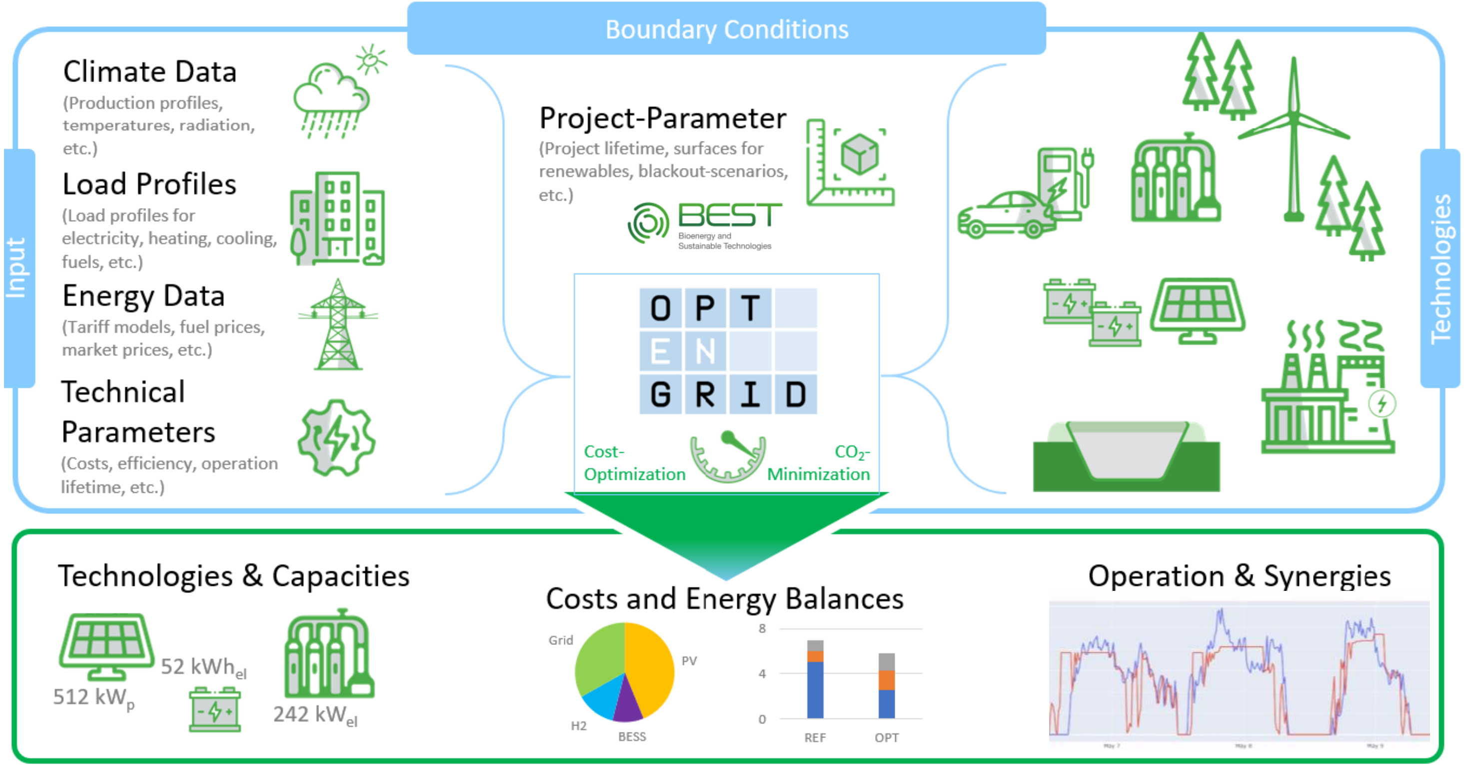
Implementation & Monitoring



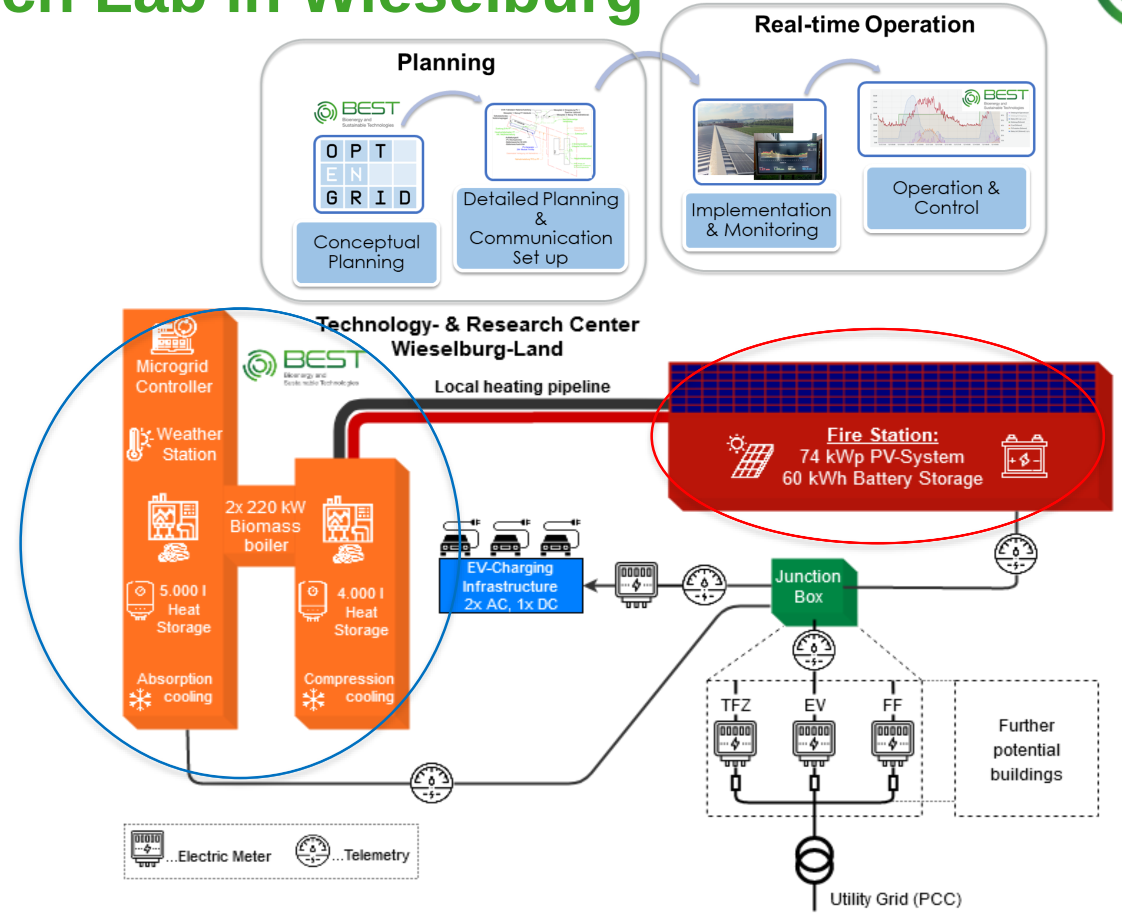
Operation & Control

Planning & Conceptualization

Optimal planning of decentral energy systems with OptEnGrid



Microgrid Research Lab in Wieselburg



Monitoring & Interfaces
Technical challenges

- To optimally operate energy technologies and flexibilities, knowledge about the **current state** → **real-time data is necessary:**
    - **Monitoring (data acquisition)** of **energy demand & production**!
- **Realization of monitoring in different projects (e.g. Microgird Lab) shows problem**:

No uniform **communication interfaces** for real-time data acquisition & control of energy technologies:

- Different manufacturers use **different interfaces**!

Monitoring & Interfaces

Development of a holistic solution for monitoring

- **Standardized data acquisition, real-time monitoring & storage** of energy data

  → **Fast implementation & scaling** !

- Built **software library for interfaces** & use of **open source standards**

  → **Cost effective solution** !

Visualization	Library for interfaces	Databases	Data Acquisition	Systems
Grafana	Modbus, M-Bus, openHAB	MariaDB, MySQL, InfluxDB, Grafana	Python	Raspberry Pi OS

Operation & Control

Adaptive forecasting methods for operation

- For **predictive control** & **optimal operation** of technologies, accurate demand & generation forecasts are necessary!
- Development of **adaptive, self-learning load & generation multi-step forecasting method** based on Machine Learning

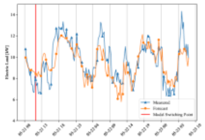
Historical & Real-Time Data

PV

Electric Load

Heating Load

Adaptive Forecasting Module



BEST
Bioenergy and Sustainable Technologies

PV Forecasting

Electic Load Forecasting

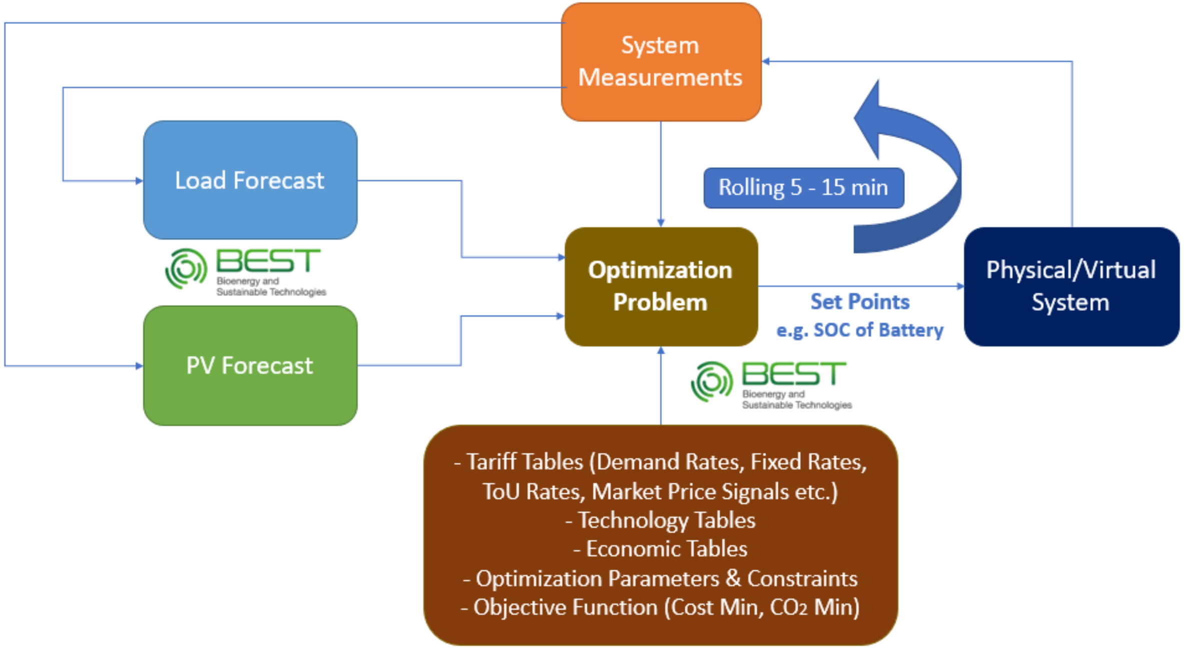
Heating Load Forecasting

48 hours-ahead Forecasts

Operation & Control

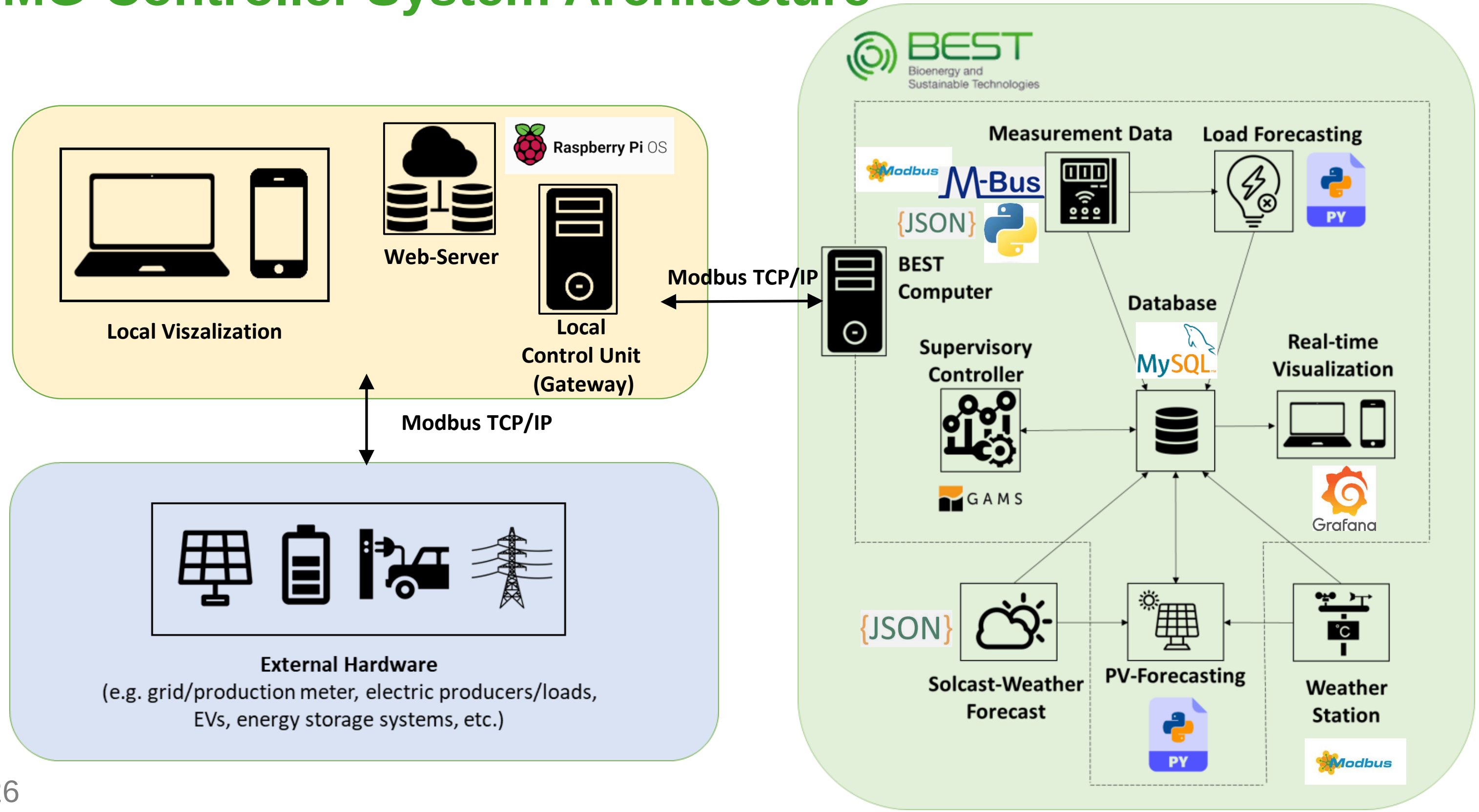
Smart- & Micrgorids (SMG) Controller Framework

- **Model Predictive Control-based optimization framework**



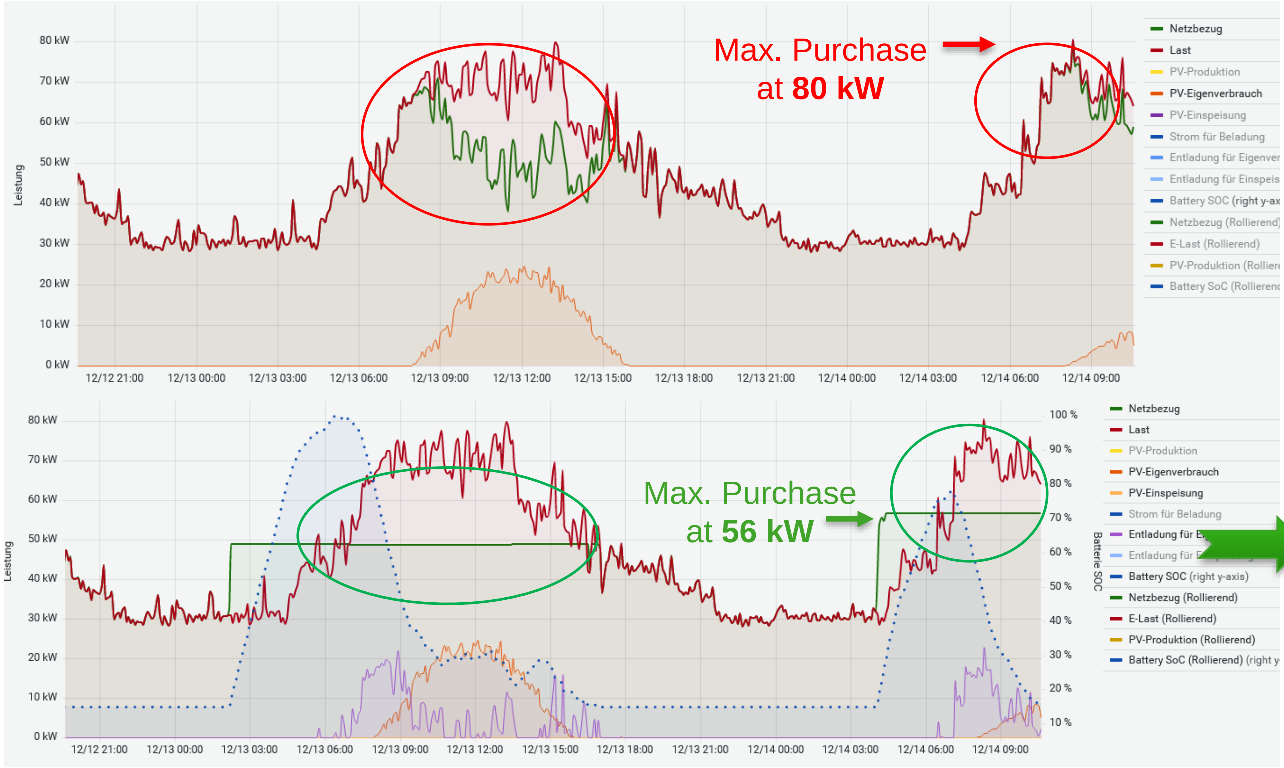
- At each time step, compute control sequence by solving optimization problem for forecast horizon
- Apply the first value of the computed control sequence
- At the next time step, get the current system state and re-compute
- **Cost** and/or **CO_2 minimization** objective functions

Optimal Operation & Control
SMG-Controller System Architecture



Microgrid Lab – SMG-Controller Test Cycles

Peak-Shaving through optimal dispatch planning



Utility Purchase (in green)
without SMG Controller

Max. Purchase at **80 kW** !

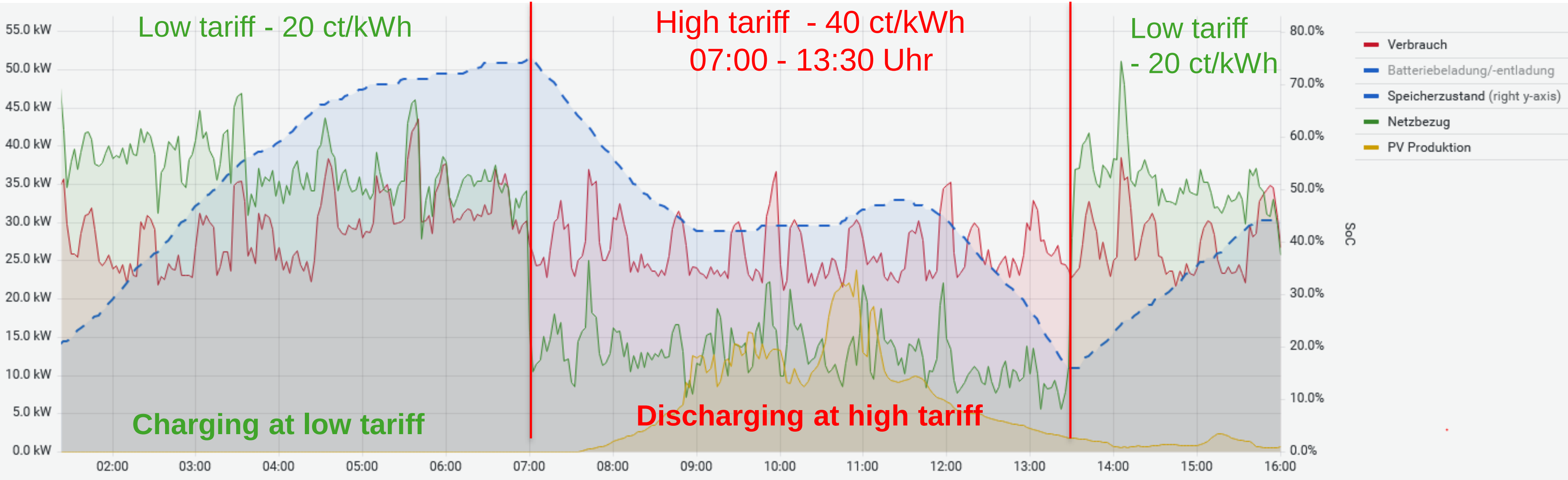
Utility Purchase (in green)
with SMG Controller

Max. Purchase at **56 kW** !
Reduction by **30%** !

Microgrid Lab – SMG-Controller Test Cycles

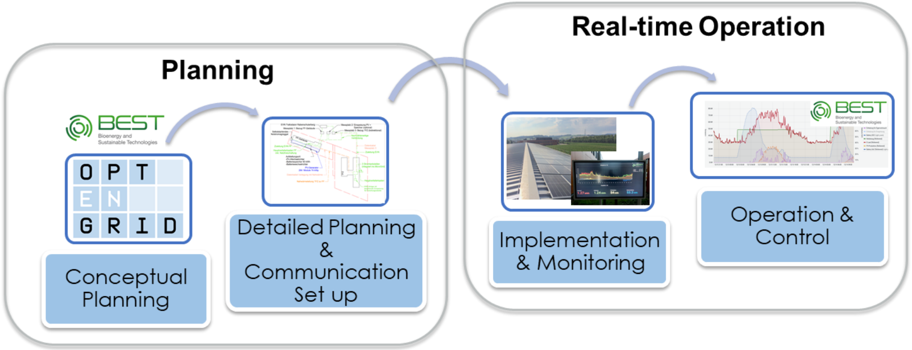
Intelligent control for time-dependent electricity tariffs

- **<u>Objective</u>: Cost Minimization with time-dependent electricity tariffs (high/low tariff):**
  Electricity purchase should be reduced as much as possible during high tariff phase by battery !
  → **Reduction** of electricity costs by approx. **15%** !



Conclusion & Outlook

- **Holistic approach** to a decentralized energy future is **necessary** for successfull implementation: Planning → Implementation/Installation → Operation & Monitoring



- **Outlook**:
  - Focus on adaptive controller solution for **Renewable Energy Communities** & **Households**
  - Developing **low-threshold (“Plug & Play”) solutions** for real-time monitoring & control of energy technologies & consumer devices (based on OpenHAB) to scale application more easily

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https://www.best-research.eu/en/competence_areas/microgrids/overview

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BEST
Bioenergy and Sustainable Technologies

Wood-Value-Tool – Techno-economic assessment of the forest-based sector

CEBC 2023, BEST day
Jan 18, 2023

Marilene Fuhrmann, Christoph Strasser,
Christa Dißauer, Doris Matschegg

FFG Forschung wirkt.
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Bundesministerium Klimaschutz, Umwelt, Energie, Mobilität, Innovation und Technologie
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Das Land Steiermark – Wirtschaft, Tourismus, Regionen, Wissenschaft und Forschung
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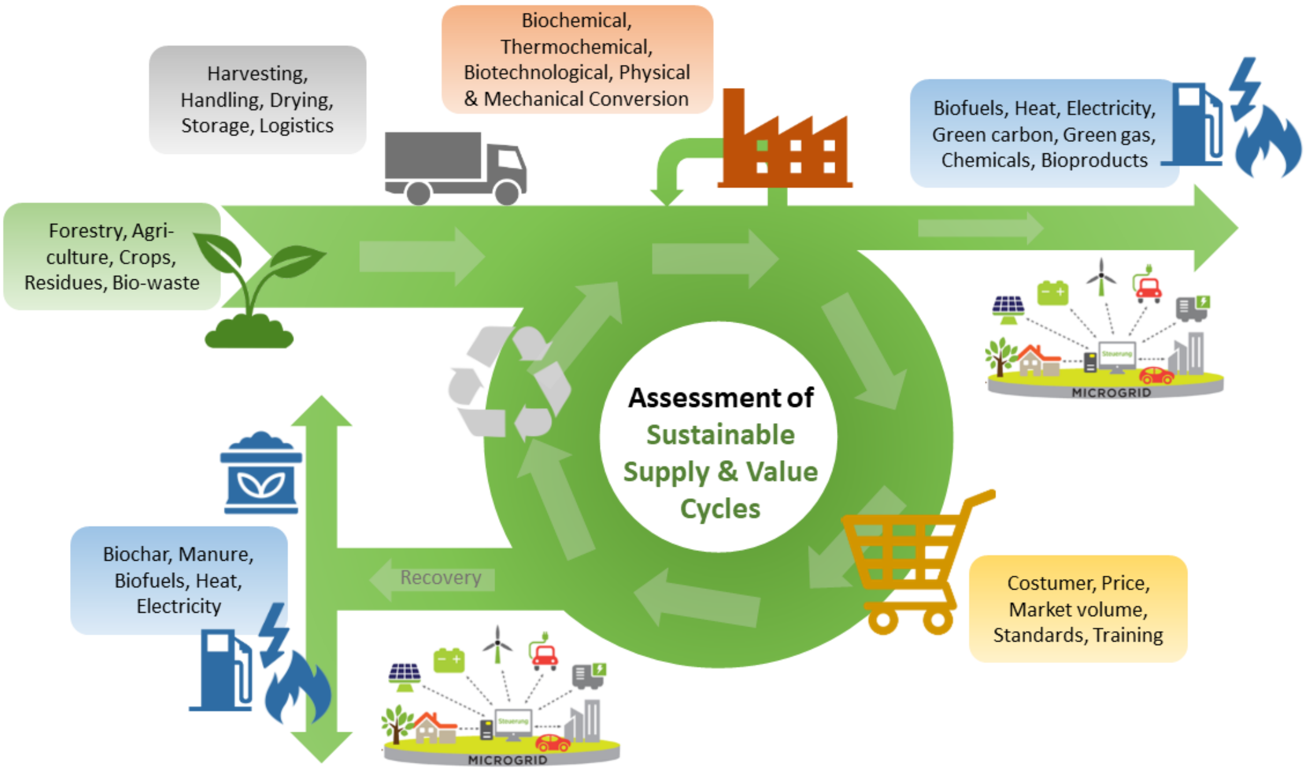
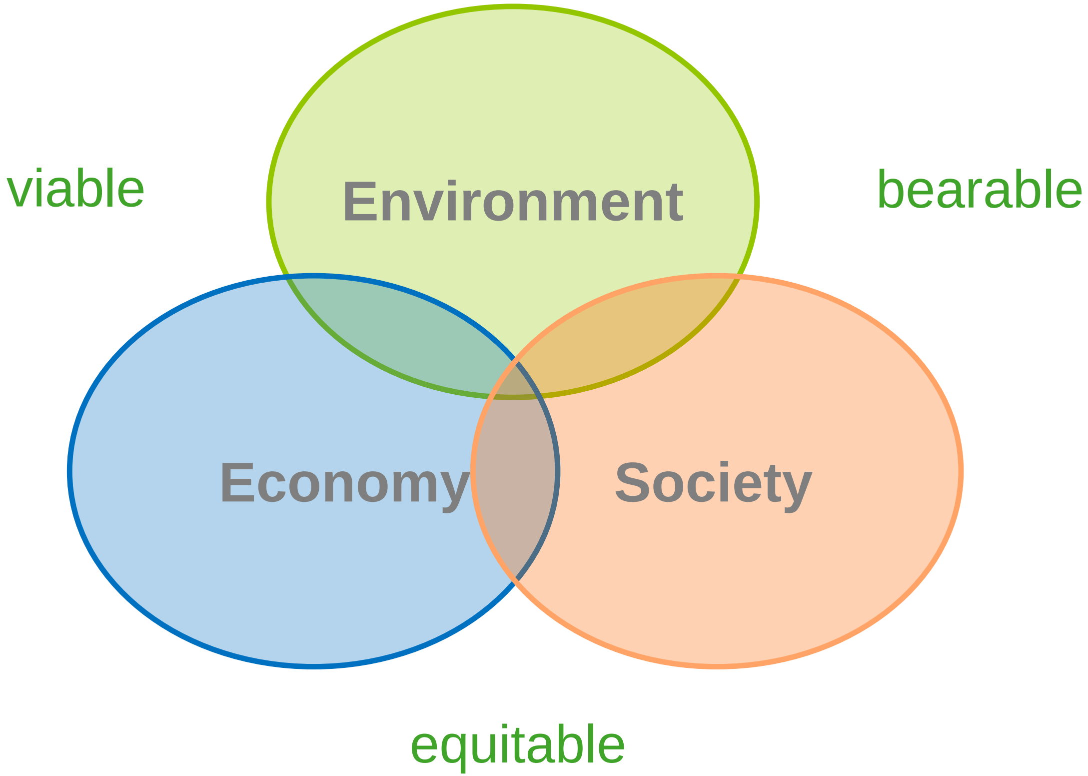
Sustainable Supply & Value Cycles



Dimensions of sustainability



Wood-Value-Tool

- Decision support tool for sustainable development of the forest-based sector in Austria
- 1st version → focus on techno-economic aspects
  - Implemented in Excel
  - Different types of woody biomass
  - Selected wood-based processes
- Next step → integration of environmental indicators

Wood-Value-Tool V1 – processes

Material sector

- Wood supply
- Pulp and paper production
- Regenerated cellulose fiber production
- Sawmill
- Particleboard production

Energy sector

- Combined heat and power
- District heating plant
- Pellet production
- Gasification + BioSNG/Fischer-Tropsch-synthesis
- Flash pyrolysis

Wood-Value-Tool V1 – raw materials

Industrial roundwod	• Sawlogs • Pulpwood round & split
Energy wood	• Firewood with bark • Forest wood chips
By-products, residues	• Sawmill by-products (wood chips, sawdust) • Bark
(Semi-finished) products	• Pulp • Pellets
Recycled materials	• Post-consumer wood • Recovered paper

→ Suitablility depending on process under consideration

→ Can easily be adapted to other feedstocks/residues

Wood-Value-Tool V1 – process specification

- Example: Wood gasification + BioSNG synthesis
- Pre-defined building blocks
- Definition of technical specifications
- Selection of raw materials
- Raw material properties defined in auxiliary table (adaptable)

TECHNICAL PARAMETERS		
TRL	8-9	
Fuel input	100	MW
Efficiency BioSNG	66	%
Total efficiency (incl. heat extraction)	86	%
Operating hours BioSNG	7 500	h/year
Operating hours heat	3 000	h/year
Lifetime of the plant	25	years

INPUT		
	Raw material	**Quality class**
Input 1	**Forest_wood_chips**	**softwood I**
Input 2	**Industrial_wood_chips**	**softwood I**
Input 3	**Bark**	**ixed I**
Input 4 (optional)		
Total input		

Pulpwood_round_and_split
Firewood_with_bark
Bark
Forest_wood_chips
Industrial_wood_chips
Sawdust
Post_consumer_wood

Specification of reference process

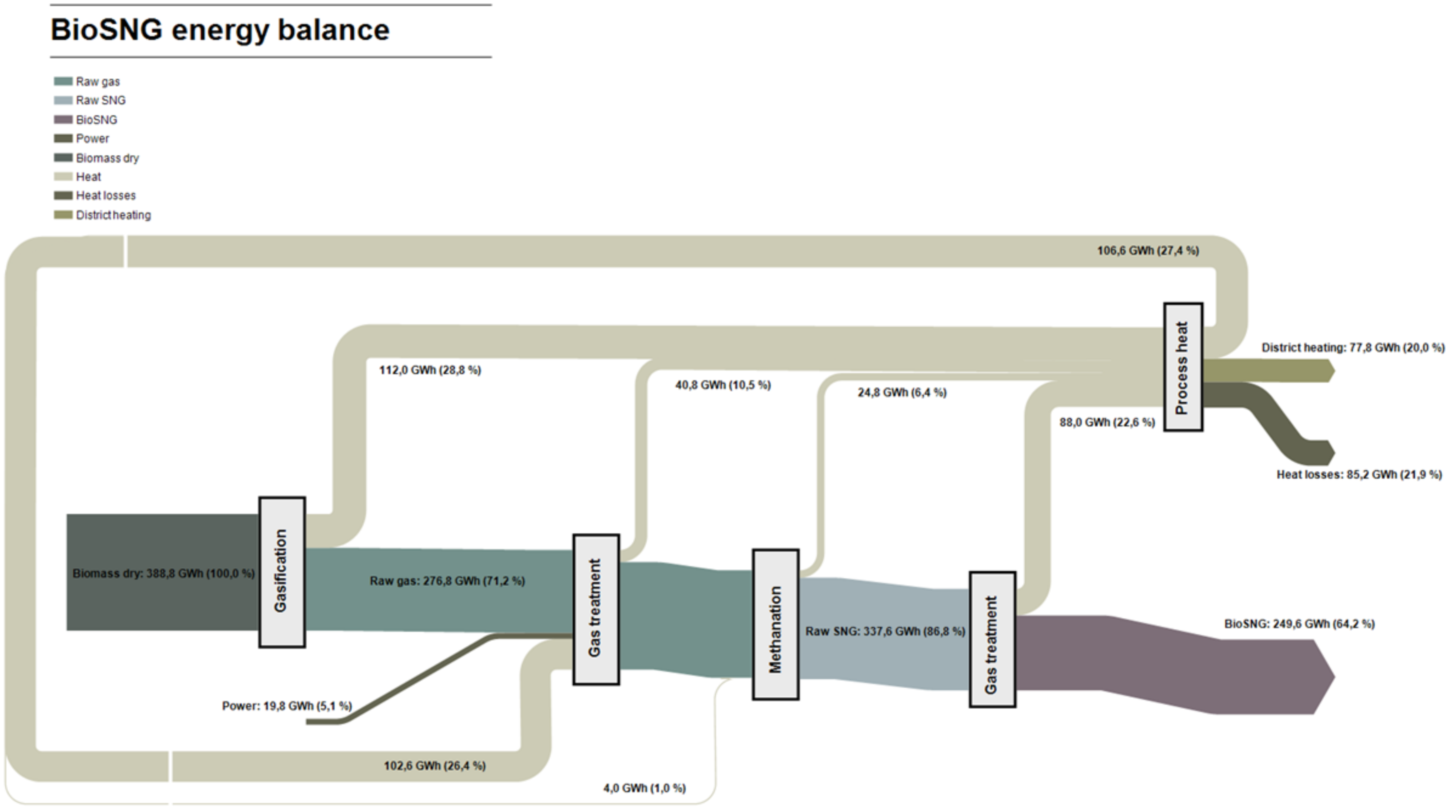
Wood-Value-Tool V1 – calculated results

- Raw material amounts based on technical specifications & raw material properties
- Cost structure (CAPEX, OPEX)
- Process output, revenues & gross profit per year and accumulated over plant‘s lifetime
- Specific production costs for assessment of competitiveness

ECONOMIC PARAMETERS		
Specific investment costs	1 824	€/kW
Total investment costs	182 400 000	€
Capital cost	11 675 782	€/a
Operating costs:	37 064 846	€/a
Raw materials	27 634 766	€/a
Operating materials	1 824 000	€/a
Disposal costs	364 800	€/a
Power	4 596 480	€/a
Personnel	820 800	€/a
Maintenance	1 824 000	€/a

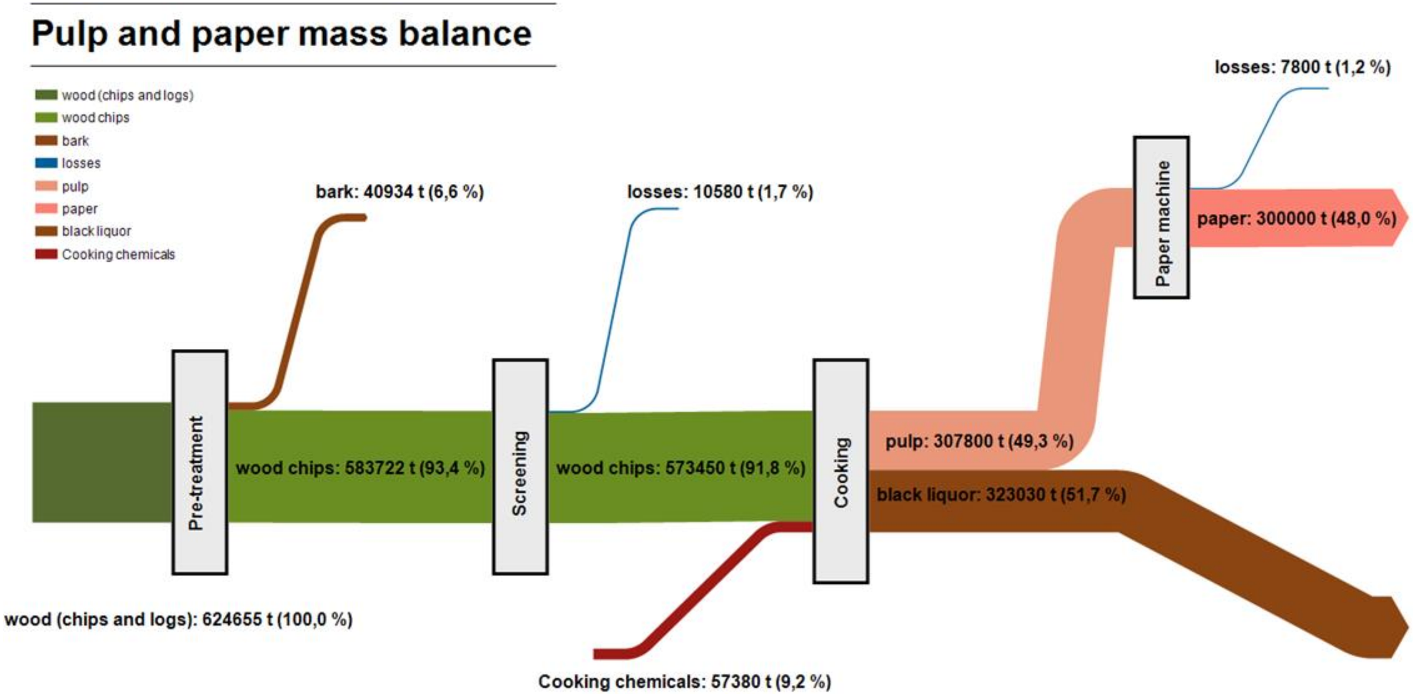
Preliminary calculation, results not ultimately valid

Wood-Value-Tool V1 – energy balance



Exemplary energy balance for reference process

Wood-Value-Tool V1 – mass balance



Exemplary mass balance for reference process

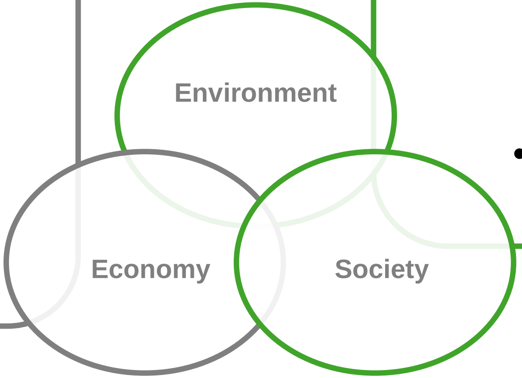
Outlook

- Extension through new processes incl. BECCS
- Integration of ecological perspective
  - Identification of relevant process-specific impact categories
  - Mostly used: Global Warming Potential as CO_2-equivalent, cumulative energy demand (CED)
  - Others: acidification, eutriphication, ozone depletion, land use change, water depletion, ecotoxicity, human toxicity …
- Identify relevant impacts on society

Overview & future perspectives

BioEcon 2019-2022

- techno-economic decision support tool
- broad range of processes & raw materials
- user friendly & easy to adapt



SusBioEcon 2023-2026

- new processes incl. BECCS & mode of transport
- integration of dimension environment
- identification of potential social impacts

Example of application:

Fuhrmann M.; Dißauer C.; Strasser C.; Schmid E. (2022): Techno-economic assessment of wood-based processes with feedstock price scenarios in Austria. Austrian Journal of Agricultural Economics and Rural Studies, Vol. 31.15: 115-122.

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